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Test method

Pulsed thermographic evaluation of disbonds in the insulation of solid rocket motors made of elastomers

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ABSTRACT

Solid rocket motors (SRMs) are key components of missiles, space rockets and shuttles. In order to prevent their combustion chamber cases from being damaged by high-temperature and high-pressure gas, they must be protected by special thermal insulation layers. Disbonds, or poor bonding in the adhesion interfaces often appear during manufacture because of technological reasons, thus possibly causing catastrophic failure of space vehicles when in operation. Pulsed IR thermography (PIRT) has been used successfully for detecting defects in aero space components due to its high productivity, one-sided access and safe exploitation. This paper describes some results of applying PIRT to the inspection of the thermal insulation of SRM cases. Particular emphasis is laid on the development of some novel approaches based on the correlation technique.

1. Introduction

Solid rocket motors (SRMs) are key components of missiles, space rockets and space vehicles. In order to prevent combustion chamber cases of space vehicles from being damaged by high-temperature and high-pressure gas, special thermal protection measures must be taken. The commonly used method is to paste an insulation layer on the inner wall of the combustion chamber. Such insulation does not only prevent the case from overheating, but also provides a cushion for the stress transfer between the case and the propellant. In addition, thermal insulation acts as a seal for filament-wound composite cases, thus being an important part of SRMs. The heat discharge in such insulation occurs through its continuous ablation and decomposition. Typical insulation produced by ablation consists of a carbon layer characterized by a high-temperature melting point to withstand high temperatures in the combustion chamber. The basic material used in manufacturing this kind of insulation is a low-density rubber-like elastomer, such as nitrile-butadiene rubber (NBR), ethylene-propylene-diene monomer (EPDM) and styrene butadiene rubber (SBR), mixed with filler, such as asbestos, silicon dioxide, Kevlar fibers and carbon fibers. Disbonds, or poor bonding in the adhesion interfaces, often appear during forming of the insulation because of technological reasons, thus possibly causing catastrophic failure of space vehicles. For instance, in 1986, the launch of the US 34D-9 rocket failed because of disbonds between the insulation layer and the case. If the defects were detected after insulation forming and before propellant filling, the insulation could be repaired by using the techniques of spreading or drilling and filling. However, nondestructive testing (NDT) of SRM thermal insulation has always been a difficult problem, especially in the case of SRMs with external thermal protection. Ultrasonic inspection is usually used in the industry even if it suffers from low

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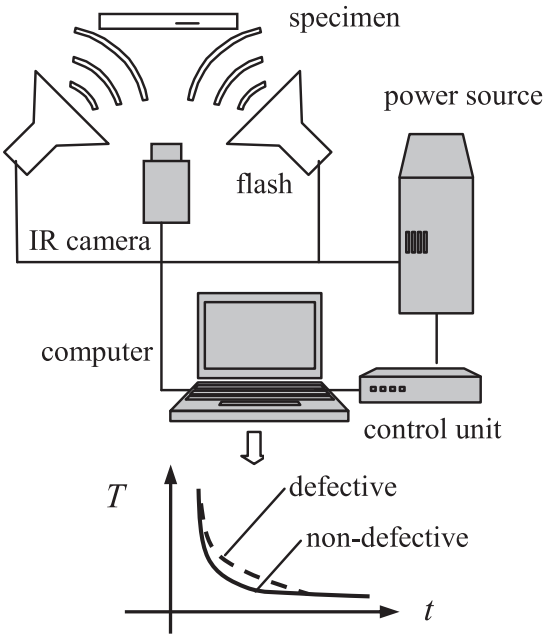

Fig. 1. PIRT unit.

productivity, contact operation and necessity for visual data interpretation. A severe drawback of the ultrasonic technique is that it cannot be applied to rocket motor cases covered with external thermal insulation which strongly attenuates or scatters ultrasonic waves. Also, its use is significantly limited if a SRM case is made of filament-wound or braided composites, or if the use of a coupling gel is forbidden to avoid surface contamination.

Non-contact NDT methods are not very typical in the inspection of SRM cases. However, infrared (IR) thermography is a promising NDT technique in this aspect. Pulsed IR thermography (PIRT) has been successfully used for detecting defects in polymers including aero space components due to its rapid testing cycle, one-sided access and safe exploitation [1–4]. Passive IR thermography is an efficient tool in the investigation of mechanical deformations and fracture analysis of polymers [5]. This paper describes some results of applying PIRT to the inspection of SRM thermal insulation.

The feasibility and reliability of thermal NDT have been evaluated by 3D numerical modeling and experimentation with correlation processing algorithms being applied in order to enhance defect detection and characterize defect parameters.

2. Experimental analysis

2.1. Experimental setup and samples

A PIRT system at Beihang University was used in the experiments. The system consists of an IR camera, two Xenon flash lamps (6 kJ of optical energy), a control unit, a computer, and processing software, as shown in Fig. 1. The IR camera with an uncooled microbolometric detector was characterized by the thermal resolution of 0.1 K, frame rate of 60 Hz and focal plane array format of 320 × 240 pixels.

Two identical reference samples were designed and manufactured to simulate SRM insulation. Both samples consisted of an internal insulation layer made of NBR, a substrate steel plate and an external protection layer also made of NBR, as shown in Fig. 2. Disbonds were imitated by embedding 0.08 mm-thick one-layer polytetrafluoroethylene (PTFE) inserts divided by two groups: round- and square-shaped. Both samples specified as 1 and 2 were

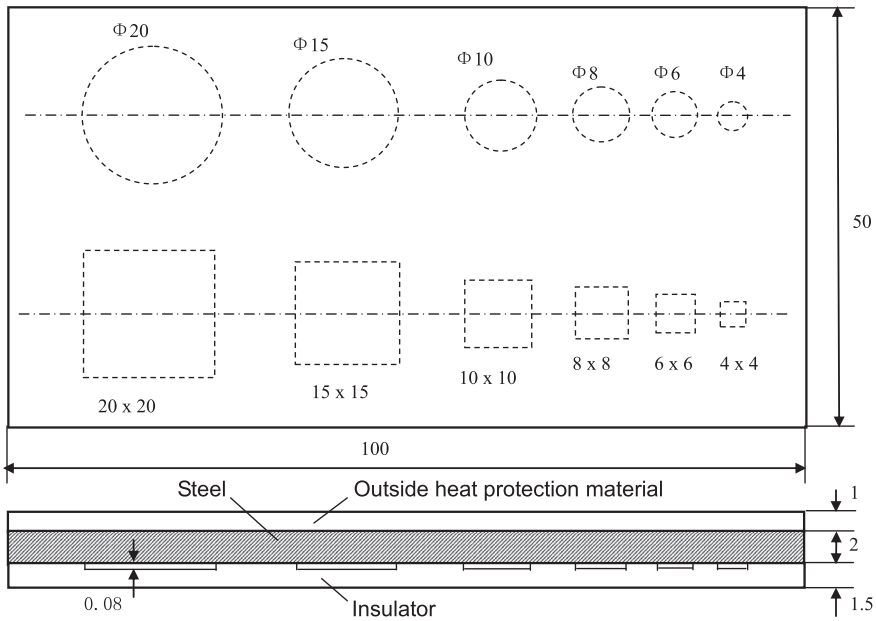

Fig. 2. Scheme of the samples (all dimensions in mm).