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Research Article

An Optical Fiber Sensor to Measure Strain in Solid Rocket Motors

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ABSTRACT

A large strain optical measurement method has been developed to determine bore strain in solid rocket motors. Based on an approach using polymeric multimode optical fibers, the strain transfer between the solid propellant and sensor is 100% and is independent of the Young's modulus of the fiber. While glass fibers would also work in this approach, polymeric optical fibers were chosen to prevent fiber fracture during installation. Calibration tests have shown a strain capability of at least 10%, and the method should be able to accommodate even larger strains. The sensor was used to monitor tangential bore strain in an inert solid rocket motor during thermal cycling, and the repeatability of the results was good, indicating little drift over the twenty hour tests. The method may also find use in other applications where a sensor is needed that not only measures large strain but retains the advantages of optical fibers.

Keywords: Strain Sensor, Optical Fiber, Rocket Motor, Bore Strain

INTRODUCTION

The propellant grain in solid rocket motors must maintain structural integrity throughout its lifetime. While in storage, natural aging results in a gradual embitterment of the propellant, which can result in bore cracks resulting from thermal stresses. These thermal stresses are the result of the different values of thermal expansion of the propellant and case, and are most serious when the motor is cooled. Since bore cracks can result in catastrophic failure of the motor during operation, solid rocket motors are usually designed using large safety factors to insure that the strains in the bore never exceed the failure strain of the propellant. Typically, designers set the bore diameter large enough so that the strain due to both thermal stresses and dynamic internal pressurization during ignition is within safe limits. On the other hand, designers would like to use the smallest bore diameter possible to maximize the volume of propellant in the motor, given a fixed case diameter. There is thus a tradeoff between safety and performance, and accurate knowledge of bore strain is critical in being able to decide on a bore diameter that represents the best balance. Determining bore strain, however, is a significant challenge. Determining bore strain resulting from thermal stress is difficult both analytically and experimentally.Calculating thermal stress from first principles requires knowledgeof several material properties of the propellant which are difficult to determine in-situ, such as coefficient of thermal expansion, Poisson's ratio, and Young's modulus. While each of these properties can be measured on samples of propellant in the laboratory, results from these tests may not be representative of the properties of the propellant in the motor, mainly since the stress state in the motor is generally three dimensional, and laboratory tests are usually performed under uniaxial stress conditions. In addition, it has proven difficult to accurately modelthe non-linear visco-elastic properties of the propellant. As a result, predictions of thermal stresses in motors are often not as accurate as desired [1,2]. Bond line stress sensors, placed between the case (or liner) and propellant can serve to validate stress predictions at the bond line, but cannot be used to measure the stress in the bore. For this reason, a way to measure bore strain or stress would be most helpful. Measuring bore strain presents several challenges. First, becausesolid propellant has a modulus orders of magnitude below that of the polyimide backing material of strain gages, 3 MPa versus 25 GPa, respectively, strain transfer to the gage from the propellant is not complete, and so the strain reading is not accurate. Second, the strains in the bore can go as high as 10%, and strain gages that can handle these strains are not readily available. Finally, use of electrical sensors is precluded due to safety concerns.

Optical fiber strain sensors would seem a logical choice for this application, but the most mature type of sensor of this type, Bragg grating strain sensors, have low strain capability and also suffer from the disadvantage of having a much higher modulus than the propellant. However, there have been reports of their use in monitoring curing of propellant, where quantitative results may notbe critical [3]. Also, the use of distributed strain measurements using glass optical fibers might be useful for qualitative studies (3a). There are reports of application of Bragg grating pressure sensors

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