Redesign of Promoted Combustion Test System: Inductance Canceling Feedthrough for Pressurized Systems

Kyle M. Sparks, *White Sands Test Facility*

Promoted combustion testing *Upward Flammability of Materials in GOX* (NASA-STD-6001, Test 17) is a standard test used to determine the flammability of metals in oxygen-enriched environments. In this testing, a metal rod of 0.318 cm (0.125 in.) diameter is forcefully ignited at varying test conditions and determined to be flammable or nonflammable. Traditionally, the test is performed with samples at ambient temperatures; however, elevated temperature testing has become of interest. We have proven that the temperature of a metal has an effect on its flammability, and elevated temperature testing is now being incorporated as a standard test parameter.

There are several approaches to heating test samples. A heating method developed by the NASA White Sands Test Facility (WSTF) in the early 1990s used an induction heater with a water-cooled coil fashioned from copper tubing; however, test pressures were limited due to the collapse pressures of the tubing. With advances in induction heater technology and with proper feedthrough and temperature control design, solid induction coils are now feasible to use, and test systems can be operated at pressures up to the maximum allowable chamber test pressures – in WSTF's case, 10,000 psi.

We overcame three major hurdles in the redesign of the heated promoted combustion test system: (1) designing an inductance-canceling induction coil feedthrough (ICF), (2) configuring an induction coil that uniformly heats a test sample rod, and (3) cooling the induction coil leads outside the test chamber. This report focuses on the design of the inductance-canceling feedthrough for pressurized systems.

When induction heater leads are oriented parallel to each other, a magnetic induction field is created. Metals within that induction field can potentially be heated. As parallel leads penetrate a pressure vessel, the metals surrounding nonmetallic seals and/or the induction leads themselves can heat to temperatures that can compromise the seals in contact with the metals, leading to pressure failures. We needed an ICF that would not heat surrounding metals, or "self-heat," to a large degree.

Using coaxial leads is one way to reduce the magnetic field energy around the outside of the leads. Theoretically, the field reduces to zero at this point; however, a field still exists within the coaxial feedthrough. Figure 1 shows the geometry and materials of construction of the coaxial feedthrough. Since induction heaters primarily heat metals, it was important to use fully nonmetallic seals.

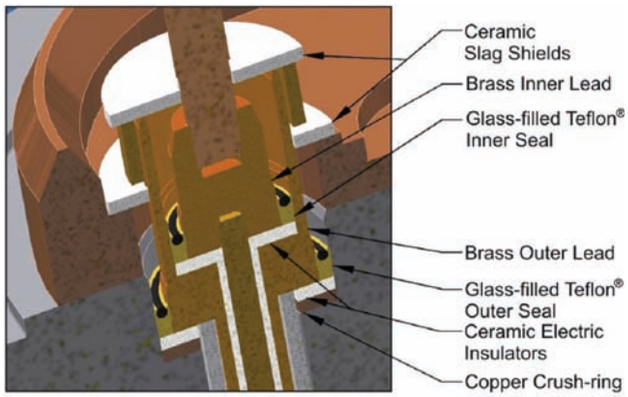

Fig. 1. *Coaxial feedthrough geometry and materials.*

We used glass-filled Teflon® pressure-activated seals with nonmetallic spring energizers for both the inner and the outer seals of the feedthrough. These seals have a working temperature up to 316°C (600°F). Ceramic slag shields keep any burning debris from contacting, and thereby failing, the seals during testing. Ceramic electric insulators must also be sized appropriately to ensure that an arc between the inner and the outer leads cannot occur.

We validated this design by testing. We placed thermocouples on various surfaces within the chamber (figure 2). The system was designed to heat a test sample via a closed-loop thermocouple attached to the upper end of the sample. We then set the desired sample temperature at the control console, based on sample temperature feedback, so the induction heater would power on and off to meet and maintain the temperature.

Technicians pressurized the test chamber to the desired test pressure using nitrogen, and the desired sample temperature was set to 704°C (1,300°F). When the sample reached its maximum temperature, we recorded data for all thermocouple channels at a 5-Hz rate for a minimum of 45 seconds. Scientists then analyzed the data and reported maximum values. Results of this can be seen in Table 1. Maximum sample

temperatures were slightly below the desired value of 704°C (1,300°F), as this was the initial testing on a redesigned system and small calibrations were needed.

The highest temperature around the seals was 81°C (177°F), far below the 316°C (600°F) maximum working temperature. These data show that the inductance-canceling feedthrough does a sufficient job of canceling any unwanted inductance that could lead to heating of the feedthrough and subsequent failure of the seals, while maintaining desired test sample temperatures. Applying the theory of coaxial cancellation proved to be a very successful method of introducing an induction heating coil into a high-pressure test system.

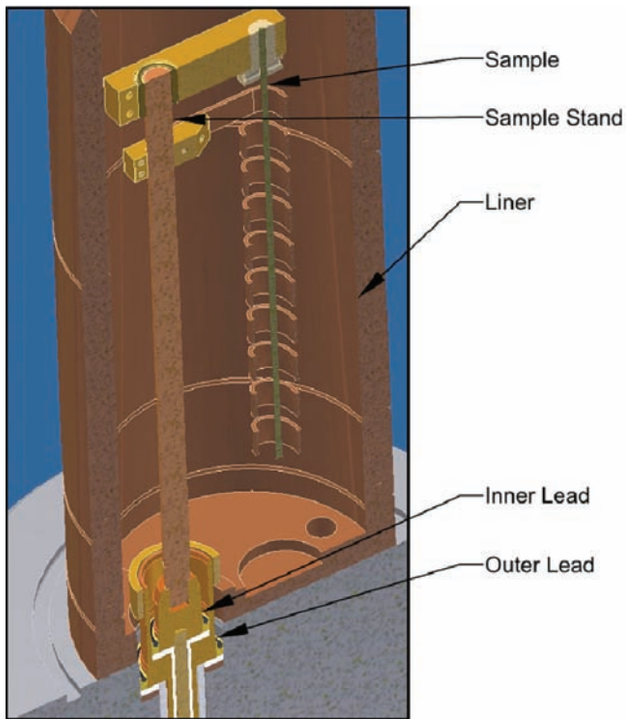

Fig. 2. *Placement of thermocouples within chamber.*

Pressure (psi)	Maximum Temperature (°F (°C))				
	Sample	Inner Lead	Outer Lead	Liner	Sample Stand
Ambient	1,228 (664)	139 (59)	112 (44)	91 (33)	139 (59)
250	1,215 (657)	137 (58)	96 (36)	92 (33)	146 (63)
1,000	1,205 (652)	154 (68)	98 (37)	102 (39)	174 (79)
5,000	1,184 (640)	154 (68)	101 (38)	104 (40)	152 (67)
10,000	1,167 (631)	177 (81)	106 (41)	109 (43)	143 (62)

Table 1. *Maximum temperatures within test chamber.*

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