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EVALUATION OF RAYTEK INFRARED PYROMETER FOR CONTINUOUS PROPELLANT TEMPERATURE MEASUREMENT

FINAL REPORT

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References: Propellant Temperature Measuring Improvement Method, Manufacturing Engineering Report No. 1542, Final Report, July 1986

<u>Process Engineering Technical Report Categories</u>
Facilities
Heat
Mixing
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Temperature

1.0 INTRODUCTION AND SUMMARY

A recommendation to install a direct line-of-sight Raytek IR pyrometer with a concentric air purge collar design in the 600-gallon propellant mixers was made in July 1986 (referenced). A prototype was recently installed in the M-24 propellant mixer to evaluate the IR pyrometer recommendation. The installation of the Raytek pyrometer is shown in Figure 1. The primary purpose of this evaluation was to determine if the IR pyrometer could be used to provide a continuous, accurate, reliable measurement of the propellant temperature during mixing. The Raytek IR infrared sensor is not recommended to be used for controlling propellant temperature nor for inspection buy-off.

The first part of the evaluation was to determine the accuracy of the sensor in measuring the propellant temperature. The second part was to determine the reliability of the air purge design in preventing contamination of the IR window. Since the Raytek pyrometer was installed in M-24, the evaluation of the sensor was limited to the following propellants produced in the Space Plant: RSRM final (TP-H1148) and Standard Missile Sustain prebatch and Final (TP-H1205C).

The results of the evaluation of the Raytek accuracy is given in Table I. This table shows the accuracy of the sensor with different propellant formulations and the overall accuracy average of ±6.2°F. As compared to the reported Raytek sensor at ideal conditions of ±3.2°F, the actual field performance is marginal. With most propellant formulation specifications having a tolerance of ±5°F for propellant temperature, it would be impossible to maintain propellant temperature control with an IR temperature sensor when the repeatability of the sensor is greater than the tolerance. Therefore, the Raytek infrared (IR) sensor is not recommended to be used for control of propellant temperature nor for inspection buy-off on target temperature. The IR sensor should only be used for indication of relative changes only.

The results of the evaluation to determine the reliability of the concentric air purge are given below. Table III gives an estimate of the frequency of dusting on the IR window on several mixes and the overall frequency of 11 AP dustings on 45 mixes. With the concentric purge design, the frequency and amount of contamination on the IR window had been reduced as compared to past designs, but the dusting had not been totally eliminated. With the frequencies given above, the use of the IR sensor would not be reliable to use for temperature propellant measurement and control.

With no instrument for continuous propellant temperature control, there still remains a need for maintaining tight temperatures throughout the mix cycle. Therefore, other alternative methods of continuous temperature measurement should still be investigated.

2.0 CONCLUSIONS

1. Although the mix temperature is periodically measured with manual thermocouples, there is still no continuous, accurate temperature measurement available during propellant mixing to maintain quality temperature and safety controls on each propellant batch.

2. Commercial IR pyrometers for use for propellant temperature measurements have inherent limitations (low energy levels at low temperature and IR energy transmission losses) that prevent the sensors at optimum conditions to be more accurate than ±1 percent (3.2°F).

3. The IR transmission losses can be minimized by using a germanium window with an anti-reflective coating. If the intrinsically safe Raytek IR pyrometer lens can be made so that the sensor is positively secured, further improvements could be made by eliminating the window that isolates the sensor from the mixing chamber.

4. The Raytek IR pyrometer at the M-24 installation cannot meet the current measurement accuracy requirement (±2°F) for propellant temperature control or inspector buy-off. The average accuracy during the three month field test was ±6.2°F.

5. The Raytek IR pyrometer does provide good indication of relative temperature changes (>8°F). This is useful for material feed indications.

6. Although the M-24 concentric air purge design for the IR window has significantly reduced the frequency of dusting of the mirror, AP dusting still continues to contaminate the window and prevents the sensor from being reliable.

3.0 RECOMMENDATIONS

It is recommended that:

1. With the inherent low temperature sensitivity and accuracy limitations with infrared sensor measurement, the Raytek infrared (IR) sensor temperature readings should not be used for control of propellant temperature nor for inspection buy-off on target temperature. The IR sensor should only be used for indication of relative changes only.

2. If an IR sensor is desired for indication of material feeding or relative temperature changes, the following should be specified for future installations:

    a. IR sensor with 8-14 micron wavelength range and digitally input emissivity and peak hold functions (Raytek or equivalent).

    b. Direct line-of-sight installation (no periscope).

    c. Specially coated germanium IR window or eliminate the IR window by positively securing the Raytek IR pyrometer (germanium lens) so that it could not fall into the mixing chamber.

    d. Vendor designed/supplied concentric air purge collar for IR window with easier access for cleaning.

    e. Install a valve in between the IR pyrometer and the mixing chamber so that the IR pyrometer could be isolated during dry powder feeding. Use the IR pyrometer only when not feeding dry powders (AP).

3. Other alternatives should be investigated for obtaining continuous propellant temperature readings.

4.0 NARRATIVE

From the referenced report, it was recommended to install a direct line-of-sight Raytek IR pyrometer with a concentric air purge collar design in the 600-gallon propellant mixers. A prototype was recently installed in the M-24 propellant mixer to evaluate the IR pyrometer recommendation. The primary purpose of this evaluation was to determine if the IR pyrometer could be used to provide a continuous, accurate, reliable measurement of the propellant temperature during mixing.

There still exists a strong need for accurate propellant temperatures during the mix cycle, especially on the Tactical formulations where the ammonium perchlorate/tepanol reactions require tight temperature control. With the reaction rate being highly temperature dependent, it has been shown that variability of the mechanical properties of the cured propellant has a direct relationship with the propellant mix cycle temperature. To a lesser extent, variability of the ballistic and processing properties is also dependent on the mix temperature, viscosity, and mix time.

The propellant temperature is a complex function of the mixing energy, the internal energy of the propellant, and the AP, as well as the heat transfer rate of the bowl jacket. Based upon past mixing experience, the operator controls the propellant temperature by adjusting the jacket water temperature. The operator only knows the actual propellant temperature at discrete moments when the mixer is stopped and a probe is inserted to obtain a temperature reading.

Past attempts to continuously monitor/control the propellant temperature have failed. A thermocouple that was installed close to the mix bowl wall had significant error because the probe more closely followed the jacket water temperature than the propellant temperature. An infrared pyrometer (Barnes) with a periscope has been found also to have significant error because of the inherently low infrared energy levels, and the frequent AP dusting of the infrared window which blocks the IR radiation (MER-1542, Final Report, June 1986). The referenced report listed several improvements that could be done with infrared pyrometers that could increase the accuracy.

The use of the infrared pyrometers is based on the theory that all objects with a temperature above 0°R emit IR radiation. Electromagnetic energy caused by thermally agitated molecules is the source of this radiation. The temperature of the emitting body determines the intensity, wavelength, and spectrum of the IR radiation. The intensity of radiation is proportional to difference between the object's temperature raised to the fourth power and the ambient temperature raised to the fourth power. A pyrometer measuring this radiation would obviously be more accurate where there is a high temperature differential between the object (molten steel) and reference temperature (ambient) as compared to the small temperature differential used for measuring the propellant temperature. An IR wavelength range of 8 to 14 micron is the typical industrial.

With the infrared radiation generating from the emitting body (propellant), the IR radiation must be transmitted to the detector on the pyrometer. There are several sources of losses as the energy is transmitted. The energy has to be either absorbed, reflected, or transmitted as it travels from the propellant mass, IR window, IR lens, and the detector itself. For the propellant measurement application, the largest sources of loss come from the propellant mass and the IR window.

The pyrometer used for this application is manufactured by Raytek, Inc and the unit is called Thermalert II. The basic components of the sensor are the germanium focusing lens, the IR detector (thermopile), ambient temperature detector, and amplifier and signal conditioner. The instrument measures the infrared energy in the 8 to 14 micron wavelength range. The germanium lens has a special anti-reflective coating to minimize the reflectance energy losses.

At optimum conditions, Raytek specifies that the accuracy of their Thermalert II instrument to be ±1.0 percent for the temperature range used for propellant. For this 320°F temperature range, this corresponds to a measurement error of ±3.2°F. To correct for IR absorption, transmission, and reflectance losses, the Raytek pyrometer has an emissivity setting that can compensate for these losses. This correction allows the pyrometer temperature to be calibrated to the actual measured temperature. Unfortunately, the emissivity algorithm used to compensate or lower apparent temperature does so by increasing the gain on the detector signal. This higher gain amplifies the measurement error of the pyrometer.

The installation of the Raytek pyrometer is shown in Figure 1. The sensor was installed in one of the 50 degree feed ports in the mixer. Because of the limited availability of the 50 degree ports, the temperature probe port was modified to include the sensor. This modification was feasible because the sensor has a 61 degree line-of-sight from vertical into the mixer while the temperature probe uses a 50 degree sight. Another feature of the installation is the IR window that separates the sensor and the hazardous mixing environment. For the Raytek pyrometer, the IR window is not required because the sensor has an intrinsically safe design for electrical hazards. The IR window is a carryover from past installations with the Barnes IR pyrometer that had electrical hazards. In an effort to minimize dusting on the IR window, a modified concentric air purge design that was modeled after a proven Raytek design was used. Raytek has a successful design in preventing dust from contaminating the Raytek detector lens in non-hazardous situations. The Raytek air purge collar could not be used for propellant operations because of the requirement for the IR window to separate the hazardous mixing chamber from the IR sensor.

The primary focus in the evaluation of the Raytek pyrometer was to determine the accuracy of the sensor in measuring the propellant temperature. The test plan developed to determine the accuracy was basically to first calibrate the Raytek pyrometer for propellant temperature measurement by adjusting the emissivity setting to account for radiation losses. Once the instrument was calibrated with a minimal bias, the IR sensor propellant temperature readings were compared to a known reference temperature over a three-month period. The reference temperatures used in the entire evaluation were the temperature probe readings that the mixing operator obtained during normal production operations (for example, the end-of-mix temperatures on the RSRM mix cycle). These digital thermocouple probes are calibrated by Metrology to an accuracy of ±2°F. A statistical analysis was performed to determine the average error in accuracy of the pyrometer.

The secondary focus in the evaluation was to determine the reliability of the air purge design in preventing contamination of the IR window. Two methods were used to determine the effectiveness of the purge. The first method was the visual examination of the IR window for contamination after the completion of a mix. The other method was to perform a trend analysis of the IR temperature data during a mix cycle. If the IR temperature reading at a fixed emissivity setting would significantly drop from the previous reading, then the cause is most likely from window contamination.

Since the Raytek pyrometer was installed in M-24, the evaluation of the sensor was limited to the following propellants produced in the Space Plant: RSRM final (TP-H1148) and Standard Missile sustain prebatch and final (TP-H1205C).

With no instrument for continuous propellant temperature control, there still remains a need for maintaining tight temperatures throughout the mix cycle. Therefore, other alternative method of continuous temperature measurement should be investigated.

During the accuracy investigation, four different materials were investigated to be used for the IR window. The selection of the IR window is critical because the IR radiation is transmitted through the IR window before the radiation is detected. If there is high transmission loss through the IR window, one would have to compensate for this loss by increasing the signal gain by decreasing the emissivity setting. By assuming that the propellant emissivity is constant, the radiation losses can be inferred. With the emissivity setting having an inverse relationship to the radiation losses, the larger the emissivity value implies a lower radiation loss. The four materials were anti-reflectance coated germanium, IRTRAN, zinc selenide, and uncoated germanium.

Table II shows the IR window material and the corresponding Raytek emissivity setting. The specially coated germanium window is the best material for a window to minimize IR losses, and the uncoated germanium is the worst material. The special coating on the window significantly increases the performance by reducing the reflectivity of the IR wavelengths. To minimize the accuracy errors caused by radiation losses, it is recommended that for future IR installations, the additional expense should be paid to allow the use of the specially coated germanium IR window. Another option is to eliminate the IR window altogether. For the Raytek pyrometer, the IR window is not required because the sensor has an intrinsically safe design for electrical hazards. The main requirement if the IR window is eliminated is that the Raytek pyrometer be positively secured so that it will not create any safety problems.

The results of the visual examination evaluation to determine the reliability of the concentric air purge are given below. For most of the six Standard Missile and eight RSRM mixes observed, there was little or no contamination on the IR window. But for one of the RSRM mixes, there was one mix found with AP dust coating the window. It is noted that this contamination was very difficult to access and clean because the viewing port had too small a diameter versus length for each cleaning. During the air purge evaluation, the purge pressure was changed to several values, and these changes had no apparent reduction in the amount of dusting on the IR window.

The trend analysis data on the concentric air purge is shown in Table III. For RSRM mixing, the contamination was inferred to occur five out of thirty-four mixes. During a casting campaign of 10 mixes per cast, there was at least one mix where dusting had occurred. For the Standard Missile Sustain prebatch mixing, the contamination was inferred to occur six out of eleven mixes. The IR window has high exposure to contamination with the Standard Missile mix cycle because it has five bins of AP that are added during mixing (one unground bin, two 13-micron bins, and two 3.2-micron bins).

With the data given in Table III, the dusting occurs approximately one out of every four mixes. With the concentric purge design, the frequency and amount of contamination on the IR window had been reduced as compared to past designs, but the dusting had not been totally eliminated. With the frequencies given above, the use of IR sensor would not be reliable to use for temperature propellant measurement and control.

TABLE I. Accuracy of Raytek IR Pyrometer With Different Propellants

Propellant/Mix Cycle		Accuracy
RSRM Main Grain TP-H1148/Final		+/- 4.8°F
Standard Missile Sustain TP-1205C/Prebatch		+/- 6.4°F
Standard Missile Sustain TP-H1205C/Final		+/- 7.4°F
	Average	+/- 6.2°F
Optimum conditions per vendor Specifications		+/- 3.2°F

Note: Raytek IR sensor had a zinc selenide window between the sensor and the mixing chamber.

TABLE II. Emissivity Compensation For IR Window Transmission Losses

IR Window Material	Average Emissivity Setting
Anti-Reflectance Coated Germanium	0.70
IRTRAN (No Longer Manufactured)	0.57
Zinc Selenide	0.38
Uncoated Germanium	0.21

Note: The IR window transmission losses have an inverse relationship with the emissivity setting. To correct the IR pyrometer temperature measurement for large transmission losses, the emissivity setting on the pyrometer must decrease.

TABLE III. Frequency of Dusting The IR Window During Propellant Mixing

Program	Mixing Date	Number of Mixes	Number Dusted
RSRM	1 Feb 1989	6	2
RSRM	7 Feb 1989	10	2
RSRM	10 Feb 1989	8	0
RSRM	17 Feb 1989	10	1
STD MIS Boost (Prebatch)	27 Jan 1989	1 (nine probes)	1
STD MIS Boost (Prebatch)	3 Feb 1989	1 (nine probes)	1
STD MIS Boost (Prebatch)	11 Feb 1989	1 (nine probes)	0
STD MIS Boost (Prebatch)	11 Feb 1989	1 (nine probes)	0
STD MIS Boost (Prebatch)	25 Feb 1989	1 (nine probes)	0
STD MIS Boost (Prebatch)	4 March 1989	1 (nine probes)	0
STD MIS Boost (Prebatch)	5 March 1989	1 (nine probes)	0
STD MIS Boost (Prebatch)	11 March 1989	1 (nine probes)	1
STD MIS Boost (Prebatch)	23 March 1989	1 (nine probes)	1
STD MIS Boost (Prebatch)	24 March 1989	1 (nine probes)	1
STD MIS Boost (Prebatch)	1 April 1989	1 (nine probes)	1
	Total	45	11

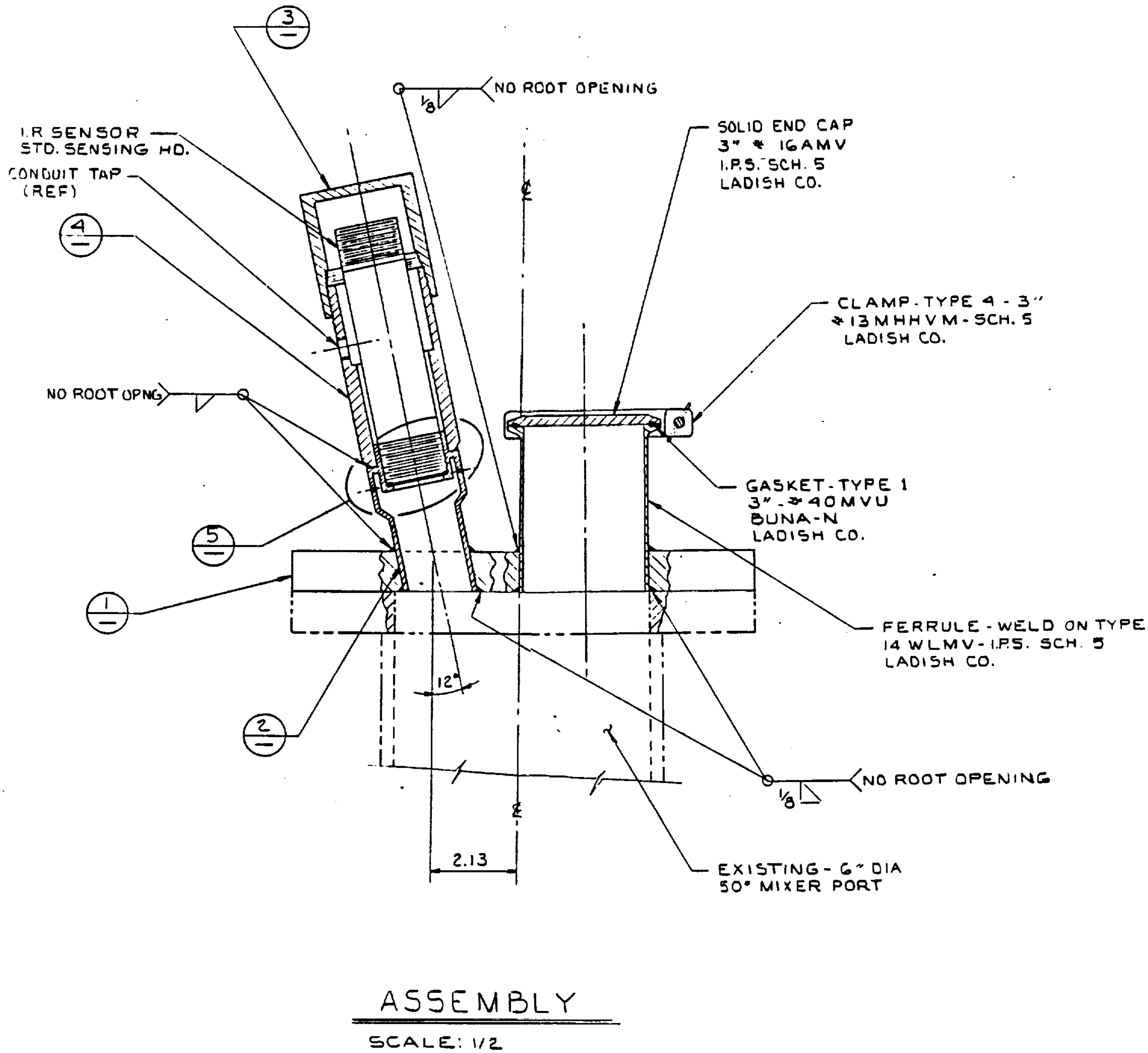

Figure 1. M-24 Mixer Raytek Infrared Sensor Installation