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Laser Ultrasonic Furnace Tube Coke Monitor
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HARVEST ENERGY TECHNOLOGY

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1.0 INTRODUCTION

This report summarizes the technical progress achieved during the seventh quarter of the ERIP project entitled, "Laser Ultrasonic Furnace Tube Coke Monitor." In Report No. 6, the primary focus involved the enhancement of the sensitivity and signal to noise ratio of the probe measurement for an ethylene cracking furnace tube at elevated temperatures.

The test results suggest that the the signal sensitivity is related to the difference between the operating temperature of the furnace tube and the melting temperature of the sacrificial stand-off. This may be due to the effect of melt viscosity on the pooling of molten metal under the stand-off or the melting rate of the stand-off. This report describes the further work performed to optimize the signal conductance of the sacrificial stand-off on an actual test furnace tube at elevated temperatures.

Project expenditures at the time of this report were approximately \$82,000. These expenditures are consistent with the project progress.

2.0 BACKGROUND

The overall aim of the project is to demonstrate the performance and practical use of a probe for measuring the thickness of coke deposits located within the high temperature tubes of a thermal cracking furnace. This aim will be met by constructing a probe that will be tested using simulated coke deposits that are positioned inside of a bench-scale furnace. Successful development of the coke detector will provide industry with the only available method for on-line measurement of coke deposits.

3.0 PROJECT OBJECTIVES

A key project objective will be to verify that the coke detector can meet specific end-user criteria needed for successful commercialization of the device including the following:

1. Sensitive measurement of coke deposits ranging in thickness from 0-1/4"
2. Suitable for use on coils of 1 1/2" - 4" diameter
3. Suitable for use at coil temperatures up to 1050°C
4. Suitable for use on rough oxidized metal surfaces
5. Instrument reliability under practical operating environments
6. Measurement reproducibility
7. The instrument is operator safe
8. The probe can be used to make random measurements down the coil length at various access angles from available furnace ports
9. The probe can operate at stand-off distances of at least 10-20'
10. The instrument package can be assembled for less than \$50,000-\$75,000

4.0 PROJECT WORK

4.1 Sacrificial Stand-Off Length

The effect of casting technique, target surface geometry, measurement angle, and surface temperature on the transducer signal response was previously investigated. The effect of stand-off length was further investigated in this work.

Standard direct contact transducers are damaged by exposure to elevated temperatures. Thus, high temperature measurements have traditionally been accomplished using a high temperature ceramic delay line (stand-off) and a high temperature couplant. However, this technique is limited to a target surface temperature of less than 1200°F and a maximum transducer temperature of 400°F. In an ethylene cracking furnace, the coil temperatures can run as high as 2000°F. To minimize the exposure of the transducer to high temperatures, it is desirable to employ a long stand-off to minimize overheating through conduction. However, increasing stand-off length results in signal attenuation.

Tests were conducted using the Bi/Sn alloy to determine the effect of stand-off length on signal attenuation. Four different test lengths were chosen ranging from 1 3/4 inch to 1 inch. The stand-off test lengths are illustrated in Figure 1.

Figure 1. Stand-Off test Lengths of 1 3/4 , 1 1/2, 1 1/4, and 1 inch.

The tests were performed on the HP45Nb furnace tube oriented in a horizontal position. The effects of damping, excitation energy, and frequency were investigated for all test

lengths to provide the optimum signal to noise ratio. Six separate tests were run at each length.

Test Results

1 ¾ " Stand-Off

The test results for the 1 ¾ inch stand-off are illustrated in Figure 2. With the exception of the main stand-off reflection and the secondary shear wave, there was no observable signal response.

Figure 2. 1 ¾ " stand-off length test results.

1 ½ " Stand-Off

The test result for the 1 ½ " stand-off length is illustrated in Figure 3. At this stand-off distance, the first indications of a tube-wall echo first become apparent at the 300 and 500 division marks. The signal to noise ratio at this stand-off length is about 2:1 which makes data difficult to interpret.

Figure 3. 1 ½ " stand-off length test results.

1 ¼ " Stand-Off

At the 1 ¼ " stand-off length, the tube wall reflections are becoming much more defined. As illustrated in Figure 4, the first three echoes are clearly discernable coming at approximately the 280, 390, and 500th division marks. Above the 500th division the noise level becomes too great to identify any further reflections.

Figure 4. 1 ¼ " stand-off length test results.

1" Stand-Off

The largest signal to noise ratio was obtained with the 1 inch stand-off length. At this stand-off distance, the tube wall reflections are clear with five discernable peaks coming at approximately the 300, 410, 520 (phase inverted), 630, and 740 division marks. The oscilloscope results for the 1 inch stand-off is illustrated below in Figure 5.

Figure 5. 1" stand-off length test results.

4.2 Vertical Incoloy Tube Thickness Verification

The first set of sacrificial stand-off tests were performed on the HP45Nb furnace tube using a horizontal tube arrangement. This initial orientation was chosen to minimize excessive melt runoff encountered in the measurement of vertical surfaces. In the horizontal tube configuration, the stand-off melt is drawn away from the target area over the convex surface by gravity. This effect is reduced as the tube size increases. In the vertical arrangement, the melt is completely free to drain away. This condition is illustrated in Figure 6 below.

Figure 6. The effect of orientation on stand-off melt runoff.

Because ethylene cracking furnace tubes are generally vertically disposed, a series of tests were conducted to evaluate the tube orientation on signal conductance.

The vertical sacrificial stand-off tests were performed on the HP45Nb furnace tube, which was heated tube was heated by conduction. The attack angle was 0° normal, and the stand-off length was 0.875 inches at the time of measurement. Figures 7 and 8 illustrate the vertical sacrificial stand-off test setup.

Figure 7. Vertical sacrificial stand-off test setup.

Figure 8. Vertical sacrificial stand-off test.

Test Results

The results from the vertical tube measurements are shown in Figure 9. There are six clear signal echoes observable starting at the main stand-off wave (zero point) arriving at the 98, 215, 325, 452, 585 (phase inverted), 709 and 835 division marks. The peaks are very well defined with a signal noise ratio of greater 4:1. The metal thickness calculations subsequently resulted in a very accurate determination that was within 0.02 mm or 0.28% error.

Figure 9. Incoloy HP45Nb tube oscilloscope results illustrating the signal reflections of a vertical furnace tube using a Bismuth / Tin couplant.

Calculated Results

$$\text{Time} = \frac{1.00 \times 10^{-8} \text{ sec}}{\text{Division}}$$

$$\text{Wave Speed in Incoloy} = 5.67 \frac{\text{mm}}{\mu\text{s}}$$

Calculated Tube Thickness

Div # 98 Delta 0

Div# 215 Delta 117

Div# 325 Delta 110

Div# 452 Delta 127

Div# 585 Delta 133

Div# 709 Delta 124

Div# 835 Delta 126

Average = 122.8

$$= \frac{(122.8 \text{ Divisions}) \left(\frac{2.00 \times 10^{-8} \text{ sec}}{\text{Division}} \right) \left(5.67 \frac{\text{mm}}{\mu\text{s}} \right)}{2}$$
$$= 6.96 \text{ mm}$$

$$\% \text{ Error} = \frac{(6.98 \text{ mm (actual thickness)} - 6.96 \text{ mm})}{6.98 \text{ mm}} \times 100\%$$
$$= 0.28\%$$

4.3 Water-Cooled Lance Design

An integrated probe tip was fabricated that incorporates a high temperature transducer. The mechanical design of the probe tip is shown in Figure 10. The probe tip consists of the transducer and the sacrificial standoff, which is housed in a spring-loaded body. The transducer is connected to a miniature air cylinder that is actuated to push the transducer outward for a controlled period of time to initiate contact with the target object.

A water-cooled lance was designed in order to cool the integrated probe tip during deployment within a hot furnace cavity. The lance insulates the integrated probe tip, that contains the transducer, sacrificial stand-off, and activation mechanism. The mechanical design of the water-cooled lance is shown in Figure 11.

The lance is outfitted with a ceramic ferrule, which when pushed up against the tube wall, will minimize thermal conduction to the probe body. A mechanical shutter is used to prevent direct radiation from the hot tube surface to the internal components contained within the probe. The shutter is momentarily actuated to an open position during the measurement process.

Figure 10. Schematic of Integrated Probe Tip

Figure 11. Water-cooled probe design.

Conclusions

The test measurements on a vertically oriented furnace tube using a sacrificial stand-off technique yielded accurate metrological data. With the appropriate stand-off length and melting temperature, the difficulties associated with ultrasonic measurements of cast materials, rough surfaces, and curved surfaces have been adequately addressed. The repeatability of the tube wall thickness measurements was verified for horizontal and vertical orientations.

PROJECT SCHEDULE AND BUDGET

The project expenditures to date are \$82,000 or about 84% of the total allocated budget. The accomplishments of the program to date are as follows:

1. Development of a novel sacrificial stand-off that can be used for contact ultrasonic measurements at high temperature.
2. Optimization of a casting procedure for production of sacrificial stand-offs having a high signal to noise ratio.
3. Fabrication of an automated probe assembly.
4. Development of an electronic control module for operation of automated probe.
5. Confirmation of the probe assembly for detecting the thickness of a simulated coke layer.
6. Confirmation of the probe assembly for accurately detecting the thickness of an actual ethylene cracking furnace tube at elevated temperatures in horizontal or vertical positions.
7. Development of a water-cooled lance design to permit furnace tube measurements in the temperature range of 1700°F to 2000°F.