**MONITORING POWER PLANT EFFICIENCY USING THE MICROWAVE-EXCITED
PHOTOACOUSTIC EFFECT TO MEASURE UNBURNED CARBON**

Quarterly Technical Progress Report

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ABSTRACT

Three test instruments are being evaluated to determine the feasibility of using photoacoustic technology for measuring unburned carbon in fly ash. The first test instrument is a single microwave frequency system previously constructed to measure photoacoustic signals in an off-line configuration. A second off-line instrument was constructed based in part on lessons learned with the first instrument, but which also expands the capabilities of the first instrument. Improvements include a control loop to allow more constant microwave power output and an ability to operate over a range of microwave frequencies. The third instrument, the on-line version of the fly ash monitor, has been designed, constructed, and initial efficiency tests have been conducted on the monitor's electrical components.

This quarter focused on improving the signal strength of the accelerometer by increasing the power level of the microwaves that induced the thermo-elastic effect, and also to conduct repeatability experiments. Efforts this quarter were spent improving the coupling of the accelerometer with the diaphragm, detecting and eliminating microwave leakage, isolating stray electrical current within the laboratory, specifically within the ground, and replacing a faulty lock-in amplifier.

Keywords: fly ash, carbon monitor, unburned carbon, boiler instrumentation

EXECUTIVE SUMMARY

The objective of this project is to explore the use of the microwave-excited photoacoustic (MEPA) effect for quantitative analysis of granular and powdered materials, and to develop an on-line carbon-in-ash monitor. The three steps to achieving this objective include: 1) designing a single microwave frequency, off-line instrument as part of proof-of-concept evaluations; 2) construction of a microwave spectrometer based on MEPA used to evaluate a variety of industrial important powders, including fly ash and pulverized coal; and 3) design and construct an on-line monitor that used MEPA technology. The instruments for steps 1 and 2 have already been completed, tested, and evaluated, and the research is currently focused on step 3, the on-line fly ash monitor.

This quarter focused on improving both the signal strength from the accelerometer, and improving the repeatability of the measurements, but several obstacles developed that had to be overcome. Of primary concern was the coupling of the accelerometer with the aluminum diaphragm. Double-sided Kapton® tape had been used to mount the accelerometer to the aluminum diaphragm, but over time the weight of the accelerometer could cause the accelerometer to become unstuck to the Kapton® tape. The use of dielectric gels were explored as a way to more securely couple the accelerometer with the diaphragm, but it was discovered that though they possessed the desired electrical properties, the gels did not form a rigid enough bond to prevent potential dampening of vibrations, so double-sided Kapton® tape proved to be the best option.

Other techniques were tried to increase the signal response. A more powerful microwave amplifier (10 W vs. 1 W) was installed as another way to increase the signal response of the accelerometer by generating more intense microwaves within the fly ash monitor, thereby increasing the thermo-elastic response of the unburned carbon in the fly ash.

It was determined, however, that the signal response from the accelerometer during this quarter was noticeably lower than the previous quarter, even when testing the same fly ashes. The on-line fly ash monitor was designed to handle either an accelerometer/diaphragm assembly, or a microphone assembly, so the accelerometer and the diaphragm were replaced with the microphone assembly in attempt to measure a photoacoustic effect rather than a thermo-elastic effect. A new situation arose, however, after the microphone was installed. The problem was before the microphone was even turned on, the lock-in amplifier was detecting a signal, and when the microphone was turned on, the signal decreased in value. Potential sources of this new problem included possible microwave leakage, electrical grounding errors (ground loops), or instrumentation errors/failures. All three sources of this new problem were explored, and it was determined that while there was some microwave leakage, the problem with the microphone was related to a ground loop identified within the laboratory. The accelerometer / diaphragm assembly was re-installed because the power supply for the accelerometer came from batteries, rather than a DC power supply, which the microphone used.

The signal output from the accelerometer, while no longer subject or influenced by any ground loops in the laboratory, was noticeably weaker than even four weeks earlier, prior to installing the microphone assembly. The reason for the weaker signal was determined to be the lock-in amplifier was no longer functioning properly. A new amplifier was purchased, tested, and shown that indeed the old lock-in amplifier was only detecting approximately 6% of the signal input, while the new lock-in amplifier responded accurately.

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INTRODUCTION

The objective of this project is to explore the use of the microwave-excited photoacoustic (MEPA) effect for quantitative analysis of granular and powdered materials. The focal point of the research centers on the measurement of unburned carbon in fly ash, an important parameter in the electric utility industry used to determine plant efficiencies. The culmination of this project will be an on-line carbon-in-ash monitor for coal-fired power plants. However, evaluations also will be made on other powdered solids, particularly coal.

The approach to this project includes work with three MEPA instruments. The first instrument is a single microwave frequency, off-line instrument built at Iowa State University as part of proof-of-concept evaluations. It is being used to evaluate precision and accuracy of the MEPA technique. The second instrument is being constructed as a microwave spectrometer based on MEPA. It will be used to evaluate a variety of industrial important powders, including fly ash and pulverized coal. The final instrument will be built based on the results of work with the previous two instruments and will be used as an on-line monitor of unburned carbon in fly ash.

EXPERIMENTAL

On-line fly ash monitor – Mechanical modifications

As described in the previous quarterly technical report, 41220R10, a primary concern was the coupling of the accelerometer with the aluminum diaphragm. Originally, double-sided Kapton® tape was used to mount the accelerometer to the aluminum diaphragm, but there were concerns that over time the weight of the accelerometer would cause the accelerometer to become unstuck to the Kapton® tape, so the use of dielectric gels were explored as a way to

more securely couple the accelerometer with the diaphragm. With technical assistance from Dow Corning, several type of materials, including Fluorogel® 4-8022, 3-1753 Conformal Coating®, and 1-2620 Dispersion® gels were tried. While all gels had the desired electrical properties, they did not form a rigid enough bond to prevent potential dampening of vibrations. It was later determined that other manufacturers' gels would have similar electrical and mechanical properties. Double-sided Kapton® tape proved to be the best option, but care taken to make sure the accelerometer is always adhered to the Kapton® tape, and firmly mounted on the diaphragm.

RESULTS AND DISCUSSION

On-line fly ash monitor – Electrical challenges

A more powerful microwave amplifier (10 W vs. 1 W) was installed as another way to increase the signal response of the accelerometer by generating more intense microwaves within the fly ash monitor, thereby increasing the thermo-elastic response of the unburned carbon in the fly ash. Significant tuning of the electrical components were required, particularly the control loop, to provide a stable power level of the microwaves. The power amplifier would saturate the control loop if the microwaves were amplified to the full 10 W, so by reducing the power level to 7 W, the power level of the microwaves remained stable. The increased power level of the microwaves initially did increase signal output from the accelerometers.

It was determined, however, that the signal response from the accelerometer during this quarter was noticeably lower than the previous quarter, even when testing the same fly ashes. There were still concerns about how well the accelerometer was coupled with diaphragm, that there may be unavoidable dampening forces present due to the weight or tension of the signal wires for the accelerometer, and that the diaphragm may not be identical from one to the next.

(Whenever the accelerometer must be removed, a new diaphragm must be installed each time the accelerometer is removed because removing accelerometer from the diaphragm creases the diaphragm.) So the accelerometer and the diaphragm were replaced with a microphone assembly in attempt to measure a photoacoustic effect, rather than a thermo-elastic effect. The microphone was powered by a DC power supply, rather than from batteries, and this seemed to introduce a new problem that was not detected before, at about the same time that a possible power surge occurred in a different laboratory in the same building, possibly due to a large arc-welder or some other heavy-current drawing device. The problem was before the microphone was even turned on, the lock-in amplifier was detecting a signal, and when the microphone was turned on, the signal decreased in value. That the power surge caused the problem has never been proven, and the source of the problem could be from several other sources as well. Alternative sources of this new problem included possible microwave leakage, electrical grounding errors (ground loops), or instrumentation errors/failures.

A spectrum analyzer with an antenna calibrated to 1 GHz was used to detect microwave leaks; power levels greater than -55 dB are most likely due to leaks. Some leakage (-40 dB) from the pre-amp was detected and the pre-amp was repaired. As a precaution, all cables that had 7 W of microwaves traveling through them were upgraded from double-shielded cables with clamped SMA connections to heavy-duty tinned-copper shielded cables with soldered SMA connections, though the power level coming out of the cables rarely exceeded -50 dB. Significant leakage (as high as -20 dB) was detected coming from certain joints/connections of the on-line fly ash monitor, so silver loaded conductive epoxy and copper tape were applied to the monitor, and the leakage reduce the leakage down to about -45 dB. These changes, while

they improved the robustness and safety of the fly ash monitor, did not eliminate the unusual signals the lock-in amplifier was receiving, so the electrical ground in the room was examined.

An oscilloscope identified two unique signals in the ground, one rather faint at approximately 30 MHz, and a second at approximately 640 kHz. After several days of examining the electrical grounds in the laboratory, and with the assistance of several electricians employed by Iowa State University, the source of the 30 MHz signal was found to be caused by an antenna effect due to a high-speed internet wire that connects an office computer to an internet hub. This signal, however, was deemed not to be the main source of the problem because the office computer had always been on in the past. The source of the 40mVpp 660 kHz signal most likely was coming from a ground wire coming from the second floor of the building where the on-line fly ash monitor resides, possibly due to an antenna effect picking up a nearby AM radio station. It was determined that the sensor (microphone or accelerometer) had to be electrically isolated from any AC grounds in the laboratory. Since the accelerometer was powered by batteries, the accelerometer and diaphragm assembly was re-installed in the fly ash monitor. Extra care was taken to make sure the wires do not add significant weight or tension, and that the diaphragms are the same size and shape as much as possible.

The signal output from the accelerometer, while no longer subject or influenced by any ground loops in the laboratory, was noticeably weaker than even four weeks earlier, prior to installing the microphone assembly. The integrity of the accelerometer was tested, and was proven to be in normal working order and in compliance with the manufacturer's specifications, so the lock-in amplifier was tested. This proved to be the cause of the weak signal. A 50 mVpp signal from a function generator was sent into the lock-in amplifier, and only a 3 mV signal was detected. The 50 mVpp signal from the function generator was confirmed as accurate using both

a hand-held multi-meter and an oscilloscope. The lock-in amplifier was no longer functioning properly.

Stanford Research Systems, the manufacturer of the lock-in amplifier, still made the identical model, so a new lock-in amplifier was purchased. Once the new lock-in arrived, which occurred at the end of this quarter, it was tested with the function generator with an input of 50 mVpp. The new lock-in amplifier responded accurately.

CONCLUSIONS AND FUTURE WORK

With the new, properly-functioning lock-in amplifier, and the ability to avoid the ground loop in the laboratory, repeatability experiments have resumed using the battery-powered accelerometer as the sensor. To incorporate active noise control, a goal described in the previous quarterly technical report, 41220R10, a new circuit board with an instrumentation-quality differential op-amp is being designed and constructed so that two accelerometers can be used in parallel, one that would be exposed to the microwave-induced thermo-elastic effect, and the other as a control sensor, to cancel out mechanical and acoustic vibrations that may be present in the laboratory, especially when the metering augers are running and the fly-ash is flowing through the fly ash monitor.