A Portable Surface Contamination Monitor Based on the Principle of Optically Stimulated Electron Emission (OSEE)

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ABSTRACT

Many industrial and aerospace processes involving the joining of materials, require sufficient surface cleanliness to insure proper bonding. Processes as diverse as painting, welding, or the soldering of electronic circuits will be compromised if prior inspection and removal of surface contaminants is inadequate. As process requirements become more stringent and the number of different materials and identified contaminants increases, various instruments and techniques have been developed for improved inspection. One such technique, based on the principle of Optically Stimulated Electron Emission (OSEE), has been explored for a number of years as a tool for surface contamination monitoring. Some of the benefits of OSEE are: it is non-contacting; requires little operator training; and has very high contamination sensitivity.

This paper describes the development of a portable OSEE based surface contamination monitor. The instrument is suitable for both hand-held and robotic inspections with either manual or automated control of instrument operation. In addition, instrument output data is visually displayed to the operator and may be sent to an external computer for archiving or analysis.

INTRODUCTION

In early 1990 an investigation began at the NASA Langley Research Center (LaRC) into the mechanisms involved in using OSEE technology for the measurement of Conoco HD-2 grease contaminant on D6AC steel substrate although other contaminants and substrates are applicable to OSEE inspection. The resulting science studies enumerated several recommended improvements to the existing commercial instrumentation [1, 2, 3, 4, 5]. These recommendations, combined with system requirements from the NASA Marshall Space Flight Center (MSFC) and Thiokol Corporation OSEE user community were used by LaRC in the design of a prototype six-channel OSEE instrument for use with robotic scanning equipment[6]. The design of the portable instrument described below was an extension of this prior work in the development of the six channel robotic version.

Some of the major recommendations for improvements cited in the science studies were a) the incorporation of a parallel electric field (PEF) configuration for the collector electrode b) a higher collector voltage c) a stable UV source and d) a dry argon atmosphere in the lamp and measurement region. The first improvement would ensure a more even distribution of the electric field thus minimizing the variation in sensitivity over the measurement region. A higher collector voltage would increase the collector current thereby improving the signal to noise ratio (SNR). Since the photo currents are linearly dependent upon the intensity of the UV source, a stable source will result in more repeatable measurements. Finally, the dry argon atmosphere is relatively non-ionizing and transparent to the UV region of interest. This will decrease the UV fluctuation due to possible absorption by oxygen and moisture in ambient air and will also decrease the photo chemistry (and hence photo fatigue) on the surface of the specimen under examination. Additional significant system requirements for the portable unit included a) a one inch diameter measurement area b) provisions for both robotic and manual inspections c) 30Hz signal bandwidth d) contamination data displayed at the instrument as well as data output capabilities e) operation in an electrically noisy environment with a minimum of 15 feet of cable between the sensor head and the control unit.

THEORY OF OPERATION

In general terms, OSEE operates by illuminating the measurement region with a source of ultraviolet (UV) radiation in the presence of a direct current (DC) electric field as shown in figure 1 [7]. The UV radiation frees electrons from the surface under inspection by the photoelectric effect. The electrons are collected on the positively charged anode, and the magnitude of the resulting current indicates the level of contamination on the surface. For the case of HD-2 grease on D6AC steel, contaminant in the measurement region absorbs the UV radiation thus reducing the number of electrons emitted from the substrate. The measured current, therefore is strongly related to the level of contaminant. The greater the current, the cleaner the sample.

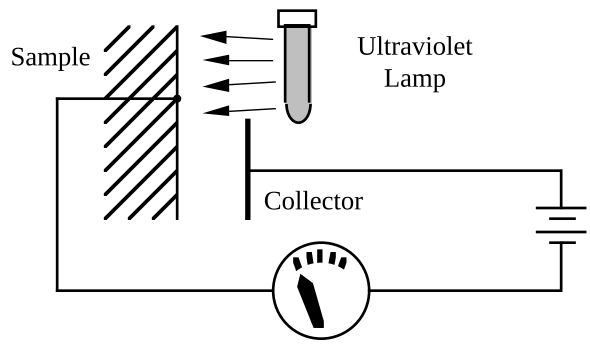

Figure 1. Basic principle of OSEE

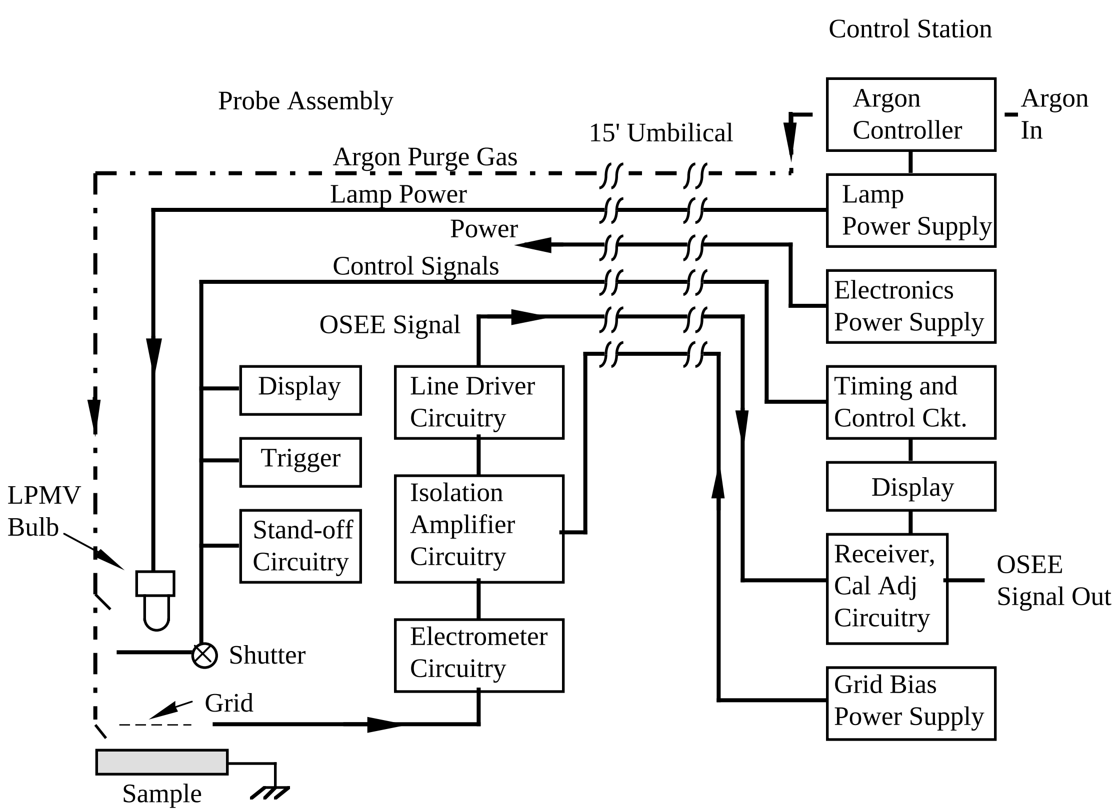

Figure 2. Block Diagram of Portable OSEE System

INSTRUMENT OVERVIEW

The instrument consists of a probe head and control station connected by a 15 foot umbilical. Figure 2 illustrates a block diagram of the instrument. The control station contains the power supplies for the lamp, grid, and associated electronics; the circuitry for system control, signal conditioning, and calibration; as well as the argon purge gas regulating system. The control station also includes the switches, indicator lamps, and meters necessary to operate and monitor the system and display the measurement results. The probe contains the UV source, electron collector grid, electrometer, isolation amplifier, and driver electronics to transmit the OSEE signal back to the control station. In addition, the probe also includes a manual trigger, a shutter mechanism to block the UV when not performing contamination measurements, and the necessary plumbing for the argon purge gas.

THE PROBE ASSEMBLY

Figure 3 shows a cross-sectional view of the OSEE probe head.

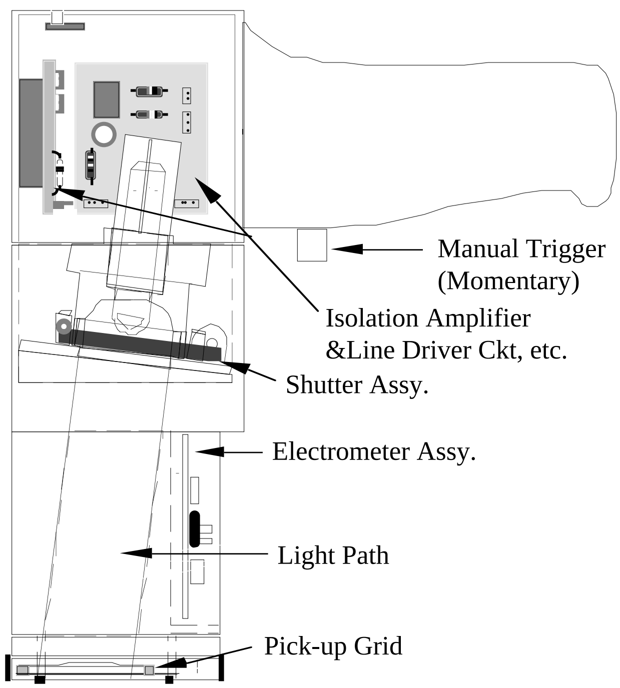

Figure 3. Cross Section of Probe Assembly

LAMP CHAMBER AND COLLECTOR

A commercially available, double bore, low pressure mercury vapor (LPMV) lamp with a lighted length of approximately 0.050 inches was chosen as the UV source. The LPMV lamp produces high efficiency UV light in distinct spectral lines. One of these, the 185 nm line, produces 95% of the OSEE response from the substrate and is also in the absorption spectrum of HD-2 grease. The lamp is powered from a high frequency power supply of approximately 40Khz to minimize interference with the low level OSEE current. One attribute of the LPMV lamp is that electromagnetic interference (EMI) emanating from the bulb is minimized by the double bore design which has a very small current loop. Additional noise reduction is achieved by surrounding the lamp chamber with an electrically grounded envelope thus shielding the sensitive probe electronics from EMI radiation. The LPMV lamp is located at the focal point of a parabolic reflecting cavity. A threaded shaft forms the lamp base which is inserted into corresponding hole in the reflector. To align the assembly, the bulb is powered and inserted into the reflector until the source is at the focal point. The reflector is fabricated from an aluminum alloy billet machined by a numerically controlled (NC) mill for a one inch maximum diameter cavity with a focal point 0.2” from the base. A flash coating of elemental aluminum is then deposited on the reflector surface and coated with a magnesium fluoride coating. Directly below the lamp/reflector assembly is an optical shutter which is opened only when a measurement is made. Undesirable reflections below the reflector are minimized by using UV absorbing materials in the lamp chamber. The lamp is recessed in the probe assembly approximately four inches from the grid. This helps produce a uniform light source and minimizes “hot-spots” on the measurement surface. The light path is angled with respect to the sensor body to permit measurements close to surface obstructions. In the bottom of the lamp chamber is a low UV attenuating, high-quality, ES grade quartz window. The collector is formed by electro-depositing a thin translucent film of chrome on the outside of the window. The benefit of this PEF geometry is that the electric field from the collector is more uniform over the illuminated surface. An annular ring of opaque chrome with a one inch inside diameter is deposited around the outer edge of the window to provide a sharp, well defined illuminated region on the measurement surface.

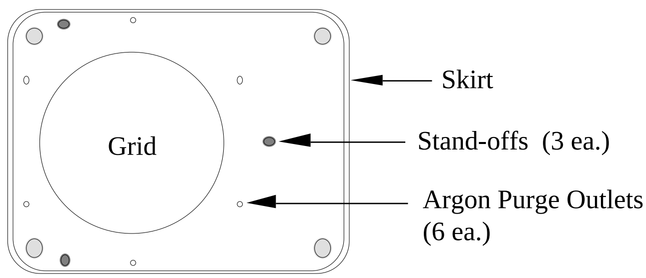

Figure 4. Bottom View of Probe

ARGON PURGE SYSTEM

In order to minimize photo chemical production and to reduce UV absorption possible with ambient air, the lamp chamber and measurement region are purged with dry argon. For the purposes of OSEE argon is non-ionizing, chemically inert, and transparent to the UV wavelengths of interest. The argon begins its journey from a pressure vessel adjacent to the control station. The flow rate is regulated at the control station and fed to the probe assembly through the umbilical. Two independent lines are used; one to supply the lamp chamber and one for the measurement region. The outlets for the measurement region are illustrated in Figure 4. Argon flows into the lamp chamber whenever the lamp is operating. In fact, when the system is turned on, the lamp is not powered up until the argon supply line and lamp chamber are properly purged. This process occurs automatically and without any operator action required. In order to conserve the purge gas, argon flow to the measurement region is switched on only when a measurement is being performed. If the argon flow should be interrupted due to an exhausted supply tank or a disconnected supply line, the lamp is automatically shut off. In addition, a flexible skirt surrounds the bottom of the sensor head to help contain the argon and minimize in impact of external air currents on the measurement process. The argon flow is regulated to approximately 100 standard cubic centimeters per minute (sccm) in the lamp chamber while the instrument is on and approximately 600 sccm in the measurement region while an inspection is being performed. This rate of consumption allows the use of small portable argon containers for extended periods of operation.

ELECTROMETER CIRCUIT

The collector electrode is connected to the electrometer circuit through spring loaded contacts soldered directly to the electrometer printed circuit board (PCB). The electrometer circuit consists of an OPA-128 electrometer grade op-amp and several passive components. The input path from the collector electrode is less than one inch long. This reduces input capacitance and EMI pick-up into the 100MΩ input impedance of the circuit. The OPA-128 has a typical input bias current of only 75fA, well below the typical collector current of 500nA. This, combined with its wide gain-bandwidth product make the OPA-128 well suited for OSEE applications. The electrometer converts the OSEE current to a voltage relative to the collector bias and sends it to the isolation amplifier stage. The entire electrometer circuit is enclosed in a separate shielded compartment at the base of the probe, further reducing EMI pick-up.

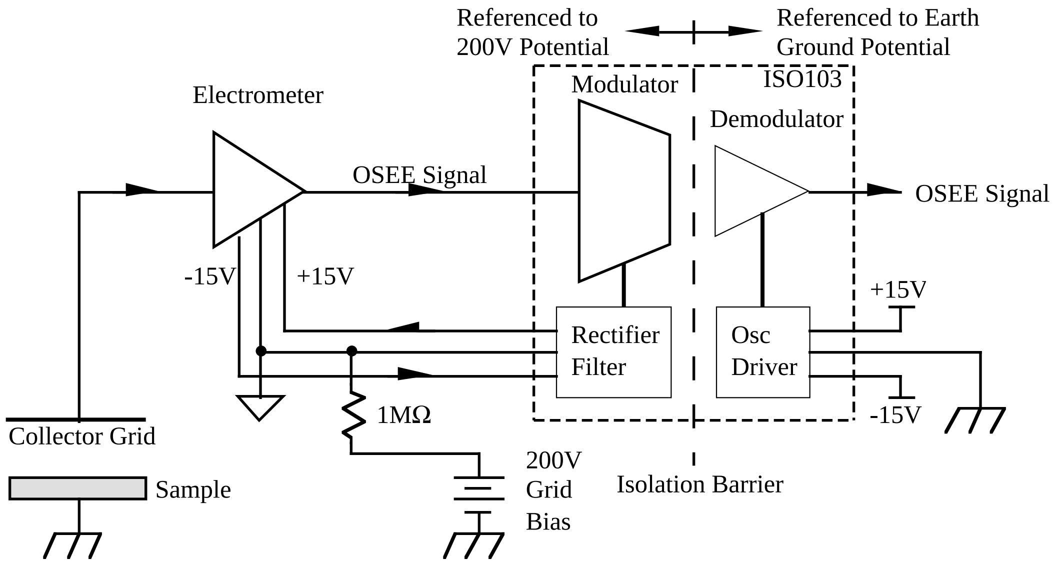

Figure 5. Block Diagram of Probe Front End Electronics

ISOLATION AMPLIFIER AND DRIVER / RECEIVER CIRCUIT

Because of the common mode measurement required for OSEE, the high collector voltage must be decoupled from the OSEE signal while maintaining the proper potential between the collector and measurement surface. A Burr-Brown ISO103 isolation amplifier was chosen for this task. Figure 5 shows the probe front end electronics and illustrates the isolation amplifier theory of operation. The ISO103 provides both signal and power across a high impedance isolation barrier. The Integrated Circuit (IC) contains an 800Khz oscillator driver on the output side of the isolation barrier. The driver is transformer coupled to the signal input side of the IC where it is rectified and filtered to provide an isolated power source for the internal and external circuitry. The input signal is modulated using the oscillator, transmitted across the isolation barrier, and demodulated on the output side. The ISO103 has an isolation barrier rated to 1500Vrms. The IC can provide isolated power up to ±15mA at ±15V for the electrometer. The 200Vdc grid voltage is applied to common on the input side of the isolation amplifier through a 1MΩ resistor. The output signal from the isolation amplifier is low pass filtered to minimize any residual oscillator feed through. The OSEE signal is then transmitted over the umbilical by a balanced line driver/receiver pair. The Analog Devices SSM-2142/1 driver/receiver pair provide a total harmonic distortion (THD) of less than 0.001% and common-mode rejection (CMR) greater then 90 db over the pass band of the system.

STAND-OFF MONITOR AND DISPLAY

Although the OSEE measurement itself is non-contacting, the signal level is inversely proportional to the square root of the stand-off distance between the collector grid and the substrate. Consequently, some means must be employed to maintain a constant stand-off during the measurement process. For situations where a robotic system is used for inspection, a proximity sensor may be used. For a manually operated instrument where the operator is placing the sensor on the substrate, three short pins protrude below the collector grid in order to maintain the proper stand-off distance (refer to Figure 4). A circuit within the sensor head detects when the stand-off pins are in contact with the substrate and illuminates a LED when the sensor is properly positioned. If so desired, the system may be configured to disable the measurement process if the sensor is not properly positioned. This minimizes errors from erroneous readings. This function is controlled via an interlock switch on the control station front panel.

Just above the stand-off LED on the sensor head, a ten-segment bar graph continuously displays the magnitude of the OSEE output signal. This provides the operator with a visual indication of contamination level without having to observe the front panel meters of the control station.

CONTROL STATION AND SYSTEM OPERATION

The control station is housed in a 14” D x 11” W x 7” H enclosure with a carrying handle. A diagram of the front panel layout is provided in figure 6. The control station has two “modes” of operation determined by a front panel switch; a scan mode and a manual mode. A second switch enables or disables the stand-off circuit interlock feature described previously. Calibration is provided by two multi-turn potentiometers which provide for adjustment of signal gain and offset. For signal display a 3 1/2 digit panel meter is used in both manual and scanning mode. An additional 20 segment bar graph meter is also enabled during scanning operation to provide contamination level trend information which would be difficult to observe from the numerical meter alone. Two indicator lamps are also mounted to the front panel; one illuminates when the 3 1/2 digit meter is updating the signal data, the other illuminates when the argon supply pressure drops below 10psi. In this condition the UV lamp is powered down in order to minimize the build-up of possible contaminants in the lamp chamber and on the collector grid due to interactions between the UV light and the atmosphere. When the argon pressure is restored, the argon umbilical line and lamp chamber are purged and the UV source is automatically powered back up.

To manually measure surface contamination, the operator places the unit into manual mode and positions the probe over the substrate until the three stand-off pins are in contact with the surface. For metal surfaces, the interlock switch is generally enabled, and the operator verifies the proper position via the illumination of the stand-off LED on the sensor probe. At the operator’s discretion, the trigger on the sensor handle is pressed which initiates a measurement cycle. First, the measurement region is purged with an argon “burp”. Next the optical shutter below the reflector is opened and the system allowed to stabilize. The OSEE signal is then sampled and the 3 1/2 digit meter is updated to reflect the latest reading. Finally, the optical shutter is closed and the argon flow to the measurement region is shut off. The display remains fixed until another measurement is taken. The entire process is performed in approximately two seconds and is independent of the duration of the trigger pull, although another sample cannot be taken until the cycle is complete and the trigger released. The OSEE signal is also present at the “signal out” jack at the rear of the control station. A “trigger out” signal on a second output indicates to an external data acquisition system when valid data is present at the output. In addition, an “external trigger” input is provided at the rear to allow for an alternate means of generating the trigger signal. This would allow for a robotic system attached to the probe to perform spot check measurements on the surface under inspection.

When the system is placed in the scan mode, argon is continuously supplied to the measurement region, and the shutter is opened indefinitely. This allows the probe to be mounted in a continuous scanning system for overall mapping of the substrate. A proximity sensor may be attached to the probe to maintain the correct stand-off distance. The interlock signal is ignored by the control station and the stand-off pins may be removed with conventional pliers. In scan mode the 3 1/2 digit meter is continuously updated at the maximum sample rate of the meter (approximately 2 samples per second), and the bar graph meter, which updates at greater than 200 samples per second, is turned on. The OSEE signal is again available at the rear of the control station.

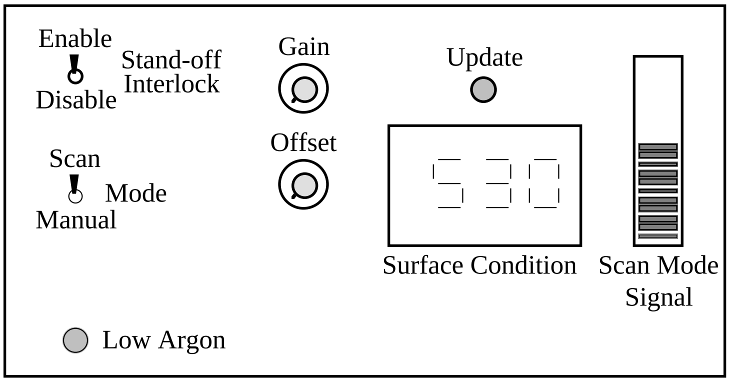

Figure 6. Front and View of Control Station

SAFETY ISSUES

Because of the potential shock hazard from the high voltage lamp and grid power supplies, several safety features have been included in the design. First, the 200V DC grid bias is resistively decoupled from the exposed collector grid through a 1 MΩ resistor. This, together with the very low input capacitance of the electrometer circuit eliminates the potential for electric shock from accidentally touching the collector grid. However, fingerprints and other foreign matter on the collector grid will result in erroneous readings. For the lamp power, an interlock system is employed which automatically shuts off the lamp power supply if lamp power connector to the umbilical is removed.

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