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The Design And Development Of A Third Generation OSEE Instrument

By
D. F. Perey
NASA Langley Research Center
Mail Stop 231
Hampton, VA 23681

W. T. Yost
F. D. Stone
NASA Langley Research Center
Mail Stop 231
Hampton, VA 23681

C. S. Welch
Applied Science Program
College of William and Mary
Williamsburg, VA 23187-8795

E. Scales
E. S. Gasser
E. Joe
T. Goodman
X. Pascual
B. Hefner
Analytical Services and Materials
Hampton, VA 23666

and

J. Bly
Lockheed Engineering and Services, Inc.
Hampton, VA 23666

Abstract

Optically Stimulated Electron Emission (OSEE) has been used to quantify surface contamination in the aerospace community. As advances are made towards the understanding of OSEE, it is desirable to incorporate technological advances with succeeding generations of instrumentation, so that improvements in the practical application of OSEE may be disseminated among the user community. Several studies undertaken by Yost, Welch, Abedin and others [1,2,3,4,5] have expanded the knowledge base related to the underlying principles of OSEE. The conclusions of these studies, together with inputs from the user community were the foundation upon which the development of a third generation OSEE instrument was based. This manuscript describes the significant improvements incorporated into a third generation OSEE instrument as well as the elements unique to its design.

Introduction

In January 1993, an OSEE team was formed at the NASA Langley Research Center (LaRC) to design and build a third generation OSEE instrument for the inspection of contaminants on solid rocket motor casings. The focus of this effort was the detection and measurement of Conoco HD-2 grease contaminant on a D6AC steel substrate although other contaminants and substrates are applicable to OSEE inspection. The instrument was to incorporate recommended improvements from the earlier NASA LaRC science studies as well as system requirements from the NASA Marshall Space Flight Center (MSFC) and Thiokol Corporation OSEE user community. Table 1 outlines the major design goals and performance specifications for the instrument as well as the results achieved. With these improvements and design goals, two complete instruments including spare parts were designed and built in nine months.

Table 1. OSEE Third Generation Performance Specifications, Design Goals, and Comparisons

Performance Specification	Design Goal	Measured Performance	Prev Generation Performance	Improvement Ratio (%)
Sensitivity (HD-2 grease)				
Range: 0 - 4 μg/cm^2	-------	0.04 μg/cm^2	1-2 μg/cm^2	> 250
Range: 4 - 30 μg/cm^2	-------	2.1 μg/cm^2	5-10 μg/cm^2	> 250
Resolution				
Contaminant (HD-2 grease)	< 1 nm	0.64 nm	3 nm	470
Spatial				
Vertical	2.5 cm	2.5 cm	15 cm	600
Horizontal	2.5 cm	0.41 cm	2.5 cm (est)	600
Reproducibility	< 1%	1.6%	10%	625
Electronics				
Noise and Hum	< -45 db	< -60 db	**	N/A
Collector Current (Nominal)	> 50 nA	500 nA	5 nA	10000
THD	< 1%	< 0.1%	**	N/A
Bandwidth	> 2 Khz	≈ 3 Khz	< 3 hz	≈ 100000
Probe Mass	< 1 Kg	1.8 Kg	> 4.55 Kg	> 250

** Not Measured

N/A = Not Applicable

The four 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 photochemistry (and hence photo fatigue) on the surface of the specimen under examination. Additional significant system requirements included a) a 1" X 1" sensor area b) six channel operation for quicker inspection c) sufficient bandwidth to allow 450 in/min minimum scan rate d) a small, light weight sensor head and e) operation in an electrically noisy environment with a minimum of 80 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 [6]. 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 amplitude of the resulting current indicates the level of contamination on the surface. For HD-2 grease on D6AC steel, the greater the current, the cleaner the sample.

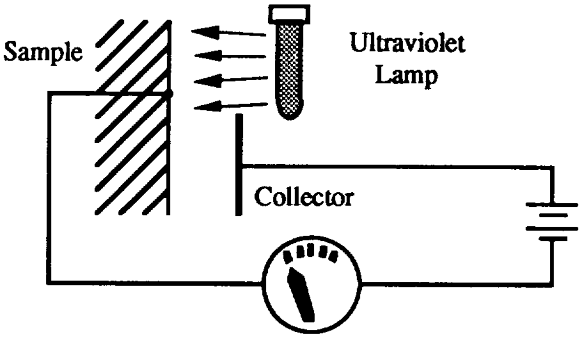

Figure 1. Basic principle of OSEE

Instrument Overview

The third generation OSEE instrument consists of a probe head and control station connected by a 90 foot umbilical. Figure 2 illustrates a block diagram of the instrument

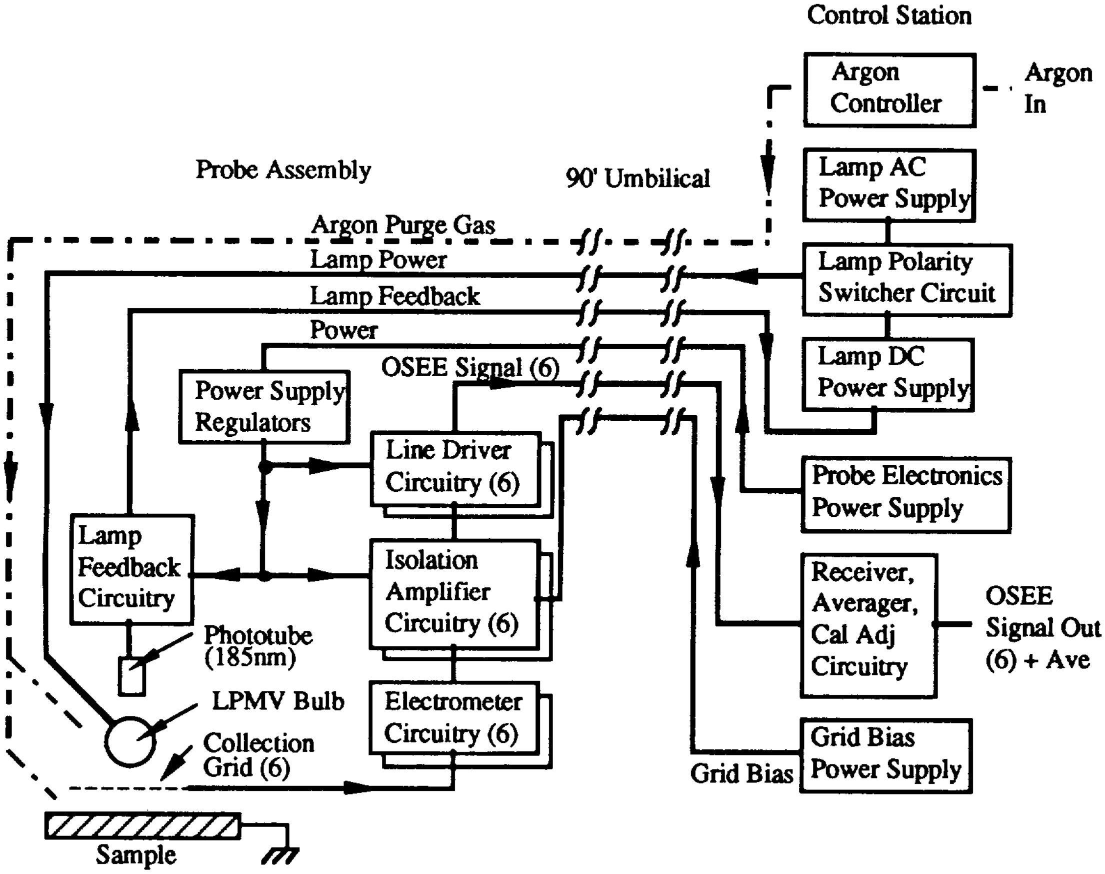

Figure 2. Block Diagram of OSEE System

The probe contains a single UV source which is controlled by a closed loop feedback circuit for lamp intensity. The UV source is common to six channels. Each channel consists of an 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 the power supply regulators and the necessary plumbing for the argon purge gas. The control station contains the lamp power supplies and control circuitry, the argon purge gas regulating system, the probe electrical power supply, grid bias power supply, and the signal receiver and instrument calibration circuitry. The control station also includes the switches, indicator lamps, and meters necessary to operate and monitor the system. The long umbilical allows the probe to be mounted on a remote scanning assembly necessary for inspecting large rocket motor casings. One of the main objectives of the design was to make the probe as small and light weight as possible in order to accommodate a variety of scanning equipment including robotic scanners, which are often limited in their ability to position heavy, bulky instruments accurately.

The Probe Assembly

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

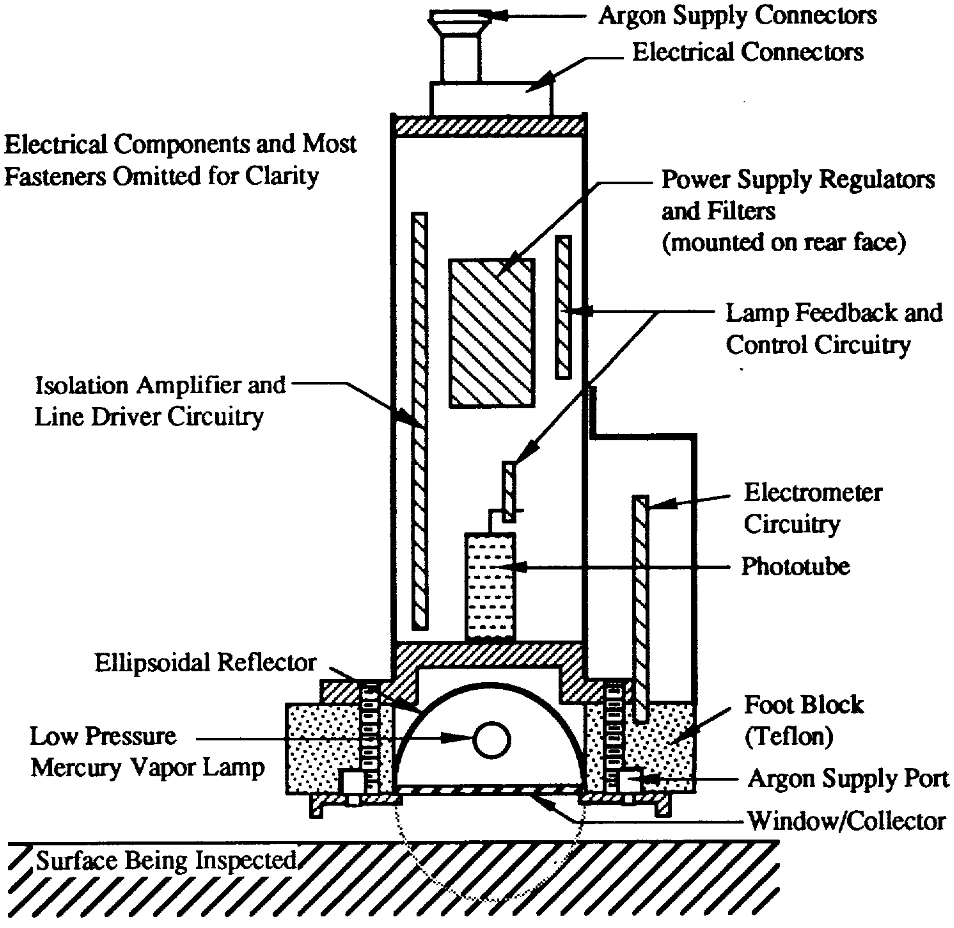

Figure 3. Cross Section of Probe Assembly

Lamp and Electrodes

A commercially available six inch long, double bore, low pressure mercury vapor (LPMV) lamp 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. Because of the wide bandwidth of the instrument, it was decided to operate the LPMV lamp in DC mode during OSEE scanning so as 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 half-ellipsoidal reflecting cavity. The reflector is fabricated with an electroformed nickel base with a highly reflective aluminum and magnesium fluoride coating. Undesirable reflections from other surfaces are minimized by coating them with a UV absorbing paint. This produces a uniform light source and minimizes "hot-spots" on the measurement surface. The bottom of the lamp chamber is a low UV attenuating, high-quality, ES grade quartz window. Six identical one inch square anodes, slightly separated and placed side by side along the length of the window make up the collectors for the six independent channels. The collectors are formed by electro-depositing a thin translucent film of chrome over a fine line nickel grid on the outside of the window. Although this configuration reduces the maximum possible UV output from the chamber, the LPMV lamp UV generation is such that it is usually operated well below its maximum output despite this limitation. The benefit of this PEF geometry is that the electric field from the collector is more uniform over the illuminated surface.

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. 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 scan is being performed. If the argon flow should be interrupted due to an exhausted supply tank or a blockage in the line, the lamp is automatically shut off.

Lamp Feedback Circuit

In order to provide a stable UV source, a feedback circuit was employed which monitors the output of the LPMV lamp at the 185 nm line and varies the input power as needed to maintain constant output intensity during OSEE scanning. A commercially available phototube with a bandwidth from 115 nm to 200 nm measures the lamp intensity. The only output from the LPMV lamp in this range is the 185 nm line. The UV reaches the detector through an aperture located at the top of the reflector with the phototube positioned just above. The output of the phototube is amplified by a Burr-Brown OPA-128 operational amplifier (op-amp) mounted directly on the phototube. The signal is then compared to a precision band-gap reference "set point." The difference becomes the error signal which is further processed before being sent to the control station via the ninety foot umbilical. Once in the control station, the signal is fed to the current limit input of a 1500V/65mA DC power supply which powers the lamp during scanning operations. The output of the power supply is sent back down the umbilical to the lamp. If the lamp intensity increases above the set-point, the current limit input to the supply is reduced, thus decreasing the input power to the lamp. If the intensity decreases, the current limit input rises and the input power increases. Typically a new lamp operates at approximately 600V @ 30mA.

Electrometer Circuit

The collector electrode is connected to the electrometer circuit through spring loaded contacts soldered directly to the electrometer printed circuit board (PCB). Each of the six identical electrometer circuits consist of one OPA-128 electrometer grade op-amp and several passive components. The input path from the collector electrode is guarded and shielded and 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 to one side of the probe, further reducing EMI pick-up.

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 4 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 (ground) on the input side of each isolation amplifier through 1MΩ resistors (one resistor for each channel) thus providing isolation between the high voltage grounds of any two channels. The oscillators for the six channels are externally synchronized to eliminate beat frequency interference. 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 together with standard Belden 8451 shielded twisted-pair cable 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.

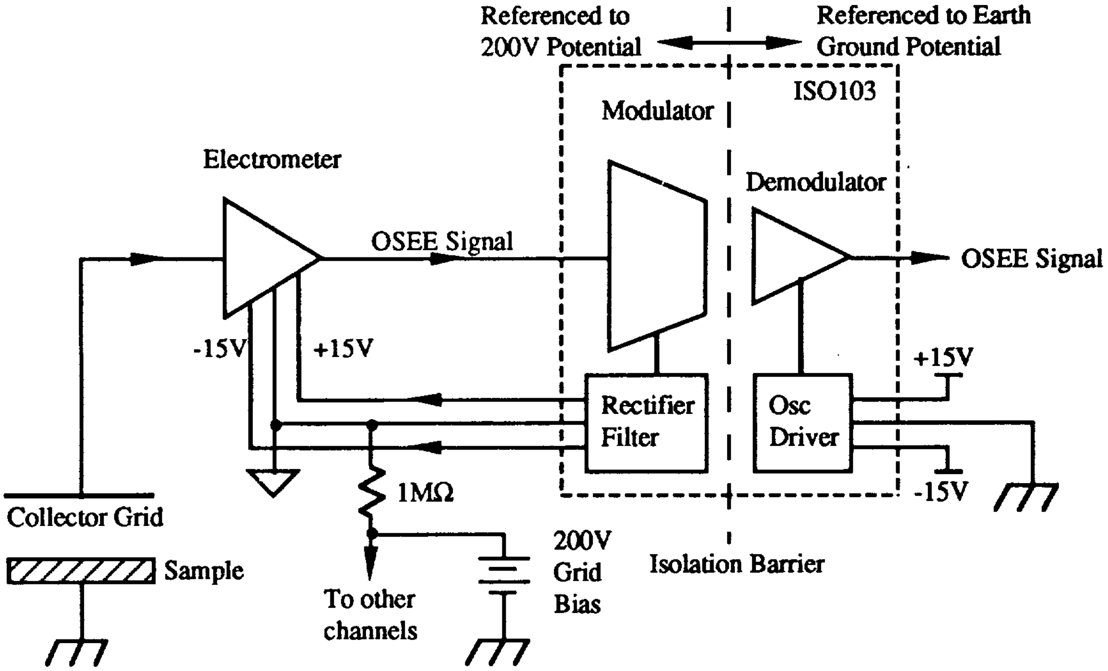

Figure 4 Block Diagram of Probe Front End Electronics

Probe Power

Electrical power for the isolation amplifier circuitry, line driver circuitry, and lamp feedback control circuitry is supplied by a regulated DC power supply located in the control station. In order to minimize EMI pickup, as well as degradation of line and load regulation performance due to the long journey through the umbilical, additional filtering and regulation are performed inside the probe assembly. This ensures ample, regulated, noise-free power for the probe in only a few square inches and one or two ounces of weight.

Control Station

The control station is housed in a 51 inch high 19 in wide standard electronic equipment rack mounted on casters. The control station has two "modes" of operation determined by a front panel switch; a scan mode and a stand-by mode. A second switch controls the flow of argon into the measurement region. When measuring surface contamination, the unit is placed in the scan mode. This allows the LPMV lamp to be operated from the DC power supply and its output regulated by the lamp feedback control circuitry. When no OSEE measurements are being made, the unit is placed in stand-by mode. This mode operates the LPMV lamp from its AC power supply, and no lamp feedback occurs. If the lamp is powered from the DC supply for more than about five minutes, then when the system is switched back to the stand-by mode, the polarity of the lamp electrodes is reversed. In doing so, the next time the unit is set to scan, the current through the lamp is reversed. By operating the lamp on AC power while idle and by reversing the polarity of the electrodes on every scan, the lifetime of the LPMV lamp may be greatly increased. Possible glitches in the OSEE signal if the polarity were switched during a scan are also eliminated.

Figure 5 provides a front and rear view of the rack. At the top of the rack, behind a blank front panel, is the controller for the argon purge gas regulators. Once the proper flow rate has been set at the time of assembly, the controller requires no further adjustment and so is normally concealed. The top rear of the cabinet contains two 5 1/4" exhaust fans to remove excess heat from the enclosure. Air is pulled in and filtered through a panel near the bottom. Below the argon controller is the control panel with the operator controls. Besides the mode and argon control switches, the control panel contains a lockable switch used to control the power to the system. "Warm-up" and "ready" indicator lamps denote system status. When first powered on, the warm-up lamp will illuminate for approximately 30 minutes to allow the UV lamp and electronics sufficient time to reach operating temperature at which time the warm-up lamp will turn off and the ready lamp will turn on until the system is shut down. Adjacent to the argon flow switch are two indicator lamps which are automatically illuminated if low argon flow is detected in either the lamp chamber or measurement region respectively. In the center of the control panel is a panel meter showing the relative condition of the UV lamp while in scan mode. Over time, as the bulb ages, the meter will move further to the right indicating that more current is being supplied to the lamp to maintain constant intensity. At sometime prior to the maximum current level, a "replace lamp" indicator adjacent to the meter will turn on, signifying that the lamp will need to be replaced in the near future (after the current scan is completed). At the far right of the control panel is an elapsed time meter which displays the accumulated time in hours that the system has been operated in the scan mode. When the system is first turned on, all the indicator lamps are powered for approximately one second so that any indicator which fails to illuminate may be identified and replaced, thus minimizing the possibility that a non-functioning indicator will jeopardize the operation of the system.

Below the control panel is the UV lamp controller and polarity switching circuit. This circuit also contains the AC lamp power supply. Below this is the DC lamp power supply, the DC power supply for the probe electronics, and the 200V DC grid power supply. All the power supplies are commercially available. A blank panel below the probe electronics power supply, conceals the rear of the receiver, signal averager, and calibration circuitry enclosure. The receiver buffers the signal from the umbilical and converts each channel to either a single or balanced output depending on the system requirements. The averaging circuit averages the six channels. The individual channel and average outputs are brought out to BNC connectors on the I/O panel at the rear of the rack. The I/O panel also contains the three electrical connectors for the umbilical and the grid bias return ground connector for the solid rocket motor casing. In order to calibrate the system, the calibration adjustment panel is removed to allow adjustment of the gain and offset of each channel. This is usually required when replacing the UV source or when using a different probe head. At the very bottom, inside the rack are the argon regulators. At the rear of the rack are the argon supply and argon umbilical connectors. All the electrical and argon connectors are unique so that the proper bulk-head receptacle is always mated with its associated connector. Just above and to the right of the argon connectors is a single standard power entry module which supplies the switched AC power to two vertically oriented power strips mounted inside the rack; one on each side.

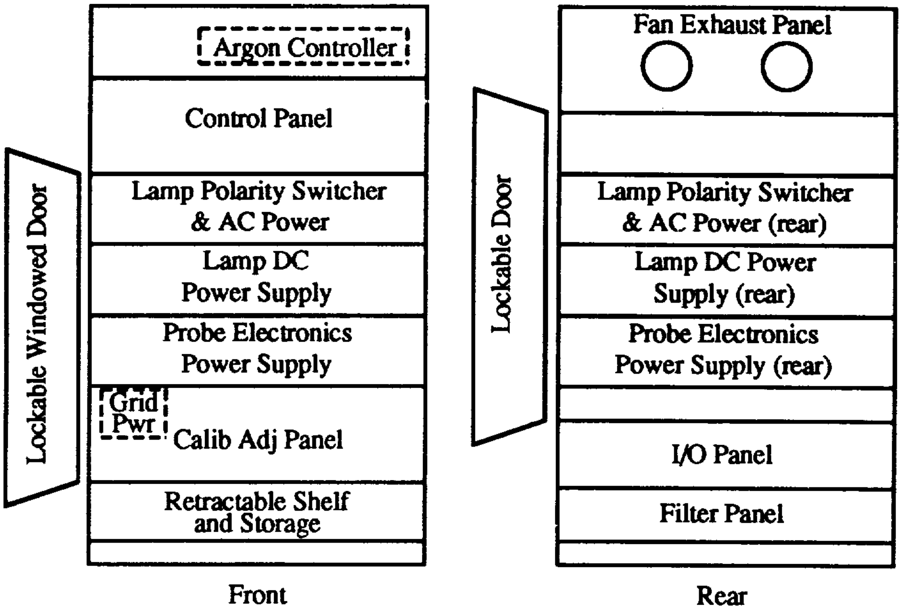

Figure 5. Front and Rear View of Control Station

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 each exposed collector grid through 1 MΩ resistors. Not only does this provide electrical isolation between the six electrodes, but it also reduces the potential for electric shock from accidentally touching any of the electrodes. 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 AC and DC lamp power supplies if any connector in the lamp power circuit path is removed.

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