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SPACE STATION SURFACE DEPOSITION MONITORING

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Abstract. Quartz crystal microbalance sensors are recommended to verify and monitor surface deposition on the early transverse boom as well as the later dual-keel Space Station configurations. Performance and placement of these sensors are discussed and compared to imposed maximum mass deposition rate requirements at the science instrument and critical power locations. Additional measurements are suggested to gain further knowledge on properties of the deposited material.

Introduction

Molecular contamination includes gases that may be adsorbed or absorbed on a surface. Film-like deposits in the liquid and solid phases are also considered molecular contamination.

The world's first space station, Skylab, included quartz crystal microbalances (QCMs) and optical witness samples to monitor contamination and its effects. Of concern to experimenters was both induced contamination and contamination from revisits by manned spacecraft. Similar concerns exist today for Space Station. Since Skylab, QCMs have been the instruments of choice for reliable, sensitive, and economical molecular mass deposition measurements both in vacuum chambers and space flight applications. A popular version utilizes thermoelectric Peltier devices coupled to the quartz crystal. In this manner, the so-called temperature-controlled quartz crystal microbalance (TQCM) can be operated over the temperature range of approximately 80°C to -60°C when the heat sink temperature is 20°C (see Figures 1 and 2).

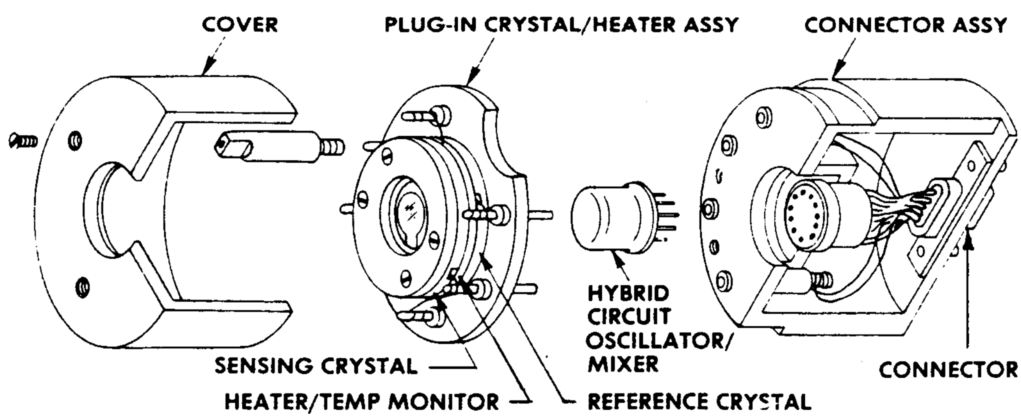

Fig. 1. Exploded View of Quartz Crystal Microbalance Sensor, QCM Research , Laguna Beach, CA

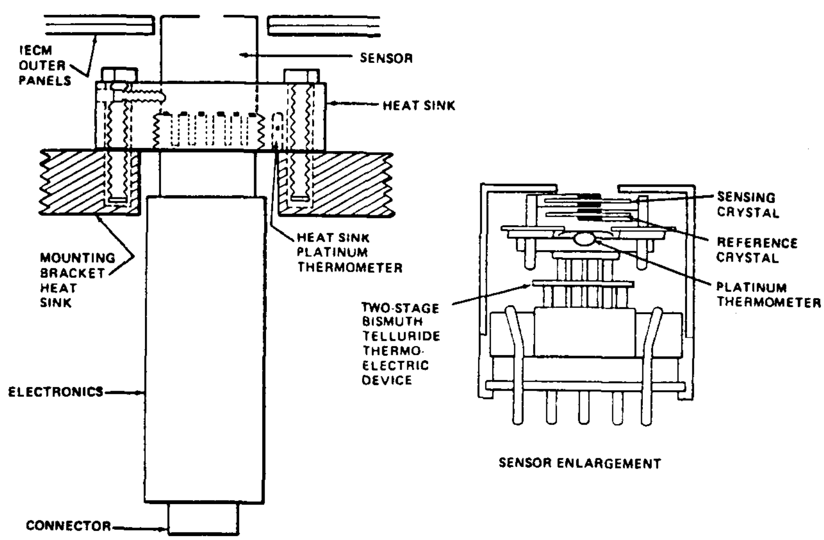

Fig. 2. Schematic of Temperature-Controlled Quartz Crystal Microbalance by Faraday Laboratories Inc., LaJolla, CA. This type was used on the Shuttle Induced Environmental Contamination Monitor (I-ECM).

Optical witness samples, where there is an opportunity for retrieval, provide an important measurement of deposition effects (this technique is used extensively during ground operations). Active monitoring of optical effects has also been accomplished and can offer real time assessment of the spectral effects of contamination depositions.

It is anticipated that the QCM will still be the instrument of choice for monitoring mass deposition in the Space Station era. Contamination level requirements must be verified, and ongoing monitoring capability must be provided to the extent that events producing undesirable levels can be abated or modified and sensitive instruments can be protected. QCM placement, type, and quantity of sensors will influence the ability to accomplish these tasks.

Requirements

The Space Station External Contamination Control Requirements Document (JSC 30426) states: ".....

4.5.1 Quiescent Periods

4.5.1.4 Molecular Deposition

The flux of molecules emanating from the core Space Station must be limited such that:

4.5.1.4A The mass deposition rate of two 300°K surfaces both located at the PMP with one perpendicular to the +Z axis and the other whose surface normal lies in the horizontal plane and at critical power locations with an acceptance angle of 2π steradian shall be no more than 1×10^{-14} g/cm^2 sec (daily average).

4.5.1.4B The mass deposition rate on a 300°K surface located at the PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 1×10^{-16} g/cm^2 (daily average).

4.5.1.4C The mass deposition rate of a 5°K surface located at the

PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 2×10^{-13} g/cm^2 sec (daily average) excluding condensation of atmospheric constituents.

4.5.2 Nonquiescent Periods

4.5.2.1 Molecular Deposition

Total deposition on sensitive surfaces such as solar arrays or either the astronomy or Earth resources observation regions shall not exceed 4×10^{-7} g/cm^2 yr.

Even though mass deposition requirements for quiescent periods (operational periods) are stated on a daily averaged 1-sec time basis, the real concern is the net deposition over longer periods of time (weeks to months). The basic detectivity of a TQCM operating at 15 MHz is about 1.6×10^{-9} g cm^{-2}. Rates of 1×10^{-14} g cm^{-2} s^{-1} (on 300 K, 2π steradian surface) would require a minimum of 44 hours to deposit 1.6×10^{-9} g cm^{-2}, and 1 year for approximately 3×10^{-7} g cm^{-2}. The latter value could be equivalent to a few monolayers and could possibly cause significant vacuum ultraviolet absorption.

A rate of 1×10^{-16} g cm^{-2} s^{-1} on a 300 K surface with an acceptance angle of 0.1 steradian would require 6 months to reach detectable limits; however, if the source can be assumed, or determined, to be isotropic over 2π steradians then a sensible detection could be attained in about 70 hours using detectors with hemispheric acceptance angles.

A more practical acceptance angle for a TQCM measurement would be 1π steradian, doubling the above sensible detection times or integration periods. Due to measurement noise and drift, another factor of 3 should be considered to establish detection and trends at these deposition rates. Thus, about 11 days would be required to establish rates of 1×10^{-14} g cm^{-2} s^{-1} 2π steradian and 18 days for rates of 1×10^{-16} g cm^{-2} s^{-1} 0.1 steradian on a 300 K surface with a 1π steradian acceptance angle.

To provide a 5 K monitor surface, in order to verify induced contaminant (excluding atmospheric constituents) mass deposition rates on cryogenic surfaces, may be prohibitively expensive. However, a radiatively cooled QCM detector could be designed that, with proper thermal shielding and efficient radiators, could provide surface temperatures down to approximately 130 K, sufficiently low to condense infrared absorbing material of interest. Radiative cooling to these low temperatures would, however, generally not allow orientation of the QCM surface perpendicular to the Z axis.

The location and orientation of the 300 K surfaces are not clearly delineated in JSC 30426. For instance, no X or Y directions are specified for the prime measurement point (PMP) surface whose normal lies in the horizontal plane, or for the surface at the critical power locations. Also, it is not trivial to distinguish the core Space Station molecular flux deposition for other sources such as science instruments. Since these instruments would by and large be mounted at the PMP, molecular flux (direct and return) from such instrumentation could be relatively high due to proximity.

Recommended Measurements

In order that sufficient information be available to determine the quantity of molecular deposition at the PMP and to possibly identify sources, it is recommended that a TQCM package consisting of six TQCMs, one viewing in each direction (±X, ±Y, ±Z), be mounted on the space and earth side on each of the 4 corners. Each sensor would view approximately 1π steradian and nominally operate at 300 K. Also, two additional TQCMs with 0.1 steradian acceptance angles should be mounted on the upper and lower booms with surface perpendicular to the Z axis and controlled at 300 K. The corner-mounted packages should be positioned such that the sensor views along the boom, i.e., science instrument area sees as many of these instruments as possible. In other words its boom area view should not be obstructed by a near-by instrument. The narrow field TQCMs should be mounted about one-fourth of the total length of the boom from each end and sufficiently above the boom to exclude direct viewing of Station components or instruments.

Two TQCMs with 1π steradian acceptance angle should be located at each of the critical power locations, one whose surface is parallel with the collector surface and the other viewing along the Y axis toward the core Station.

QCMs are currently available with the capability of operating at 5 K. However, it is recommended that this measurement await the installation of a cryogenic instrument located at the PMP. Otherwise, this requirement has little or no basis and would require expensive plumbing. As mentioned above, a radiatively cooled QCM would partially fulfill this measurement requirement.

JSC 30426 does not address the external contamination control requirements for the early configuration transverse boom Station. For instance, the PMP is not defined, but it is assumed that these points are located on the Earth and space sides (with surfaces perpendicular to the Z axis) and are between the module area and the rotation joint for the solar panels. It is also assumed that the deposition rate requirements at the PMP are the same as for the dual-keel Station.

System Design and Operation

The recommended TQCM's require nominal temperature control of the collection surface (crystal) at 300 K. To minimize power requirements the TQCM sensor packaging should be deisgned to provide heat sink temperatures of about 300 K.

Three channels of data are required for each sensor:

(1) frequency between collection and reference crystals - 16 bit s^{-1} maximum, 12 bit s^{-1} nominal, (2) sensor temperature - 8 bits resolution, (3) heat sink temperature - 8 bits resolution.

Sensor crystal heat frequency and temperatures would only be queried infrequently at, say intervals of tens of minutes to obtain sufficient deposition information. Nonquiescent periods, during Space Shuttle visits for example, would require greater sampling frequency (on the order of minutes) to resolve deposition from various activities (proximity operation, docked periods, astronaut EVA's, etc.). Heat sink temperature could be obtained by a single measurement on each of the packages of 6 TQCM's.

Table 1 gives additional pertinent information on TQCM's.

It is recommended then, for similarity and continuity between the early and later Station configurations, that the same package of six TQCMs discussed above be placed on the +Z and -Z sides of the boom about half-way to the rotation joint on the +Y and -Y axes (i.e., a total of four packages). At least one 0.1 steradian TQCM should be placed near each of these locations. All of the above would be nominally controlled at 300 K. Measurements for the critical power locations would be the same as for the dual-keel Station above.

Table 1. Typical TQCM Specifications Sensor.

Sensor:	
Mass Sensitivity	1.6×10^{-9} g cm^{-2} Hz^{-1} (15 MHz crystal)
Temp. range	80° to 60°C (20°C Heat Sink)
Sensor Power	0.15 watts
Peltier Power	0 - 7 watts
Dimensions	3.2 cm diam. x 7.5 cm long
Weight	120g
Controller (For approx. 6 sensors):	
Dimensions	15 x 16 x 16 cm
Weight	3 kg
Rough-order-of-magnitude cost:	
Contoller, 6 sensors - $150K	

Additional Measurements

Two additional measurements are proposed to gain more knowledge of the nature of the deposited mass and the effects of these deposits on optical properties.

The first measurement requires a TQCM mounted adjacent to a neutral mass spectrometer and the capability to mechanically flip the TQCM 180° so that its collection surface is positioned directly over the entrance aperture of spectrometer. Heating the TQCM would allow analysis of collected mass and possible insight into subsequent surface chemistry. TQCM heating rates could be controlled to accommodate the mass spectrometer sweep rates. When gases are no longer evolving, the TQCM is repositioned in the collection mode and commanded to the desired collection temperature.

Prior to installation of extremely sensitive ultraviolet-vacuum ultraviolet (uv-vuv) instruments on the Station it would be desirable to measure the optical effects of deposition directly and inexpensively. A prototype instrument has been developed by Acton Research Corporation, Acton, Massachusetts, under a Small Business Innovative Research contract and technically monitored by MSFC that provides the capability to measure specular transmittance and reflectance at 10 discrete wavelengths over the 121.6 to 210.0 nm region. Up to three samples are mounted in a carousel and exposed to the environment. Optical measurements can be accomplished quickly on any sample at any selected wavelength, sequenced through all the samples at each of the 10 wavelengths, or in a user preprogrammed mode.

These two additional measurements would provide complementary information to that provided by the QCM. We would then have mass, mass spectra, and optical effects as a function of time.

SECTION 2: CONTAMINATION CONTROL REQUIREMENTS

Introduction

This section contains the material from that portion of the workshop that addressed the Space Station External Contamination Control Requirements Document: JSC 30426 (November, 1986). The first paper in this section reviews the various suggested modifications to JSC 30426. This is followed by a summary of these suggestions and the disposition recommended by the working group. Also included in this section is a study of the allowable build up of neutral gases near high voltage sources such as the solar arrays. This study was in two parts: first, R. Rantanen has modeled the predicted build up near the solar arrays for various conditions (see section 5 of the paper by R. Rantanen). Secondly, in a separate paper, N. Singh has computed the levels at which plasma arcing and discharges could be expected to take place.

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