University of Arizona
College of Optical Sciences

Opti 521 – Paper summary
Eduardo Bendek – November 30, 2009

Paper Title:

"Reduction of flight hardware outgassing after integration under a less stringent requirement"

Authors:

David W. Hughes, Glenn P. Rosecrans, Jack J. Triolo and Patricia A. Hansen.

Association:

Swales and Associates, Inc. and Goddard Space Flight Center

Abstract

In preparation for the Hubble Space Telescope (HST) second servicing mission, hardware was refurbished and cleaned to meet a requirement more than an order of magnitude cleaner that the original requirement. The Fine Guidance Sensor (FGS) radial bay module is located in close proximity to the HST science instruments; therefore the contamination sensitivity of the second servicing mission science instruments necessitated the establishment of new FGS contamination requirements. These new requirements are based on a critical optics temperature of -88° C while the original FGS outgassing requirements were based on protecting the HST primary mirror, which has an average temperature of +10° C. A contamination reduction plan was prepared resulting in the use of molecular absorbers and bake out temperature within 1° C of the maximum survival temperature of the hardware. Final contamination measurements are within 3% of the predicted levels and meet the second servicing mission contamination requirements.

1 Background

The HST contains three Fine Guidance Sensors (FGS) and five scientific instruments. During the second servicing mission one FGS was replaced together with the installation of other instruments. The contamination budget for the WFPC-2 is the most stringent, allowing 1% throughput reduction per month (reversible) on the -88° C CCD window.

The FGS light entrance aperture is open to the space shared by all science instruments apertures and pick-off mirrors. The FGS core is a graphite epoxy optics bench which is surrounded by a heater shroud which is covered with multi layer insulation (MLI).

The FGS that was installed during this mission is the first one which has been refurbished because it was built before the first generation instruments requirements was established and therefore the outgassing requirement is based on the impact on the HST primary mirror contamination.

This spare FGS to be installed in this mission has an outgassing rate of 3.4×10^{-7} g/s on a -88° C Quartz Crystal Microbalance (QCM). Then the decision was to clean it to achieve the requirement of the newer FGS which was set to 2.08×10^{-8} g/s with a QCM at -65° C

2 Contamination reduction plan

Analysis of the outgassing rate of the FGS at its bakeout temperature indicated that more than six months of bakeout would be required to meet the outgassing requirement since the outgassing temperature is only 29° C. Alternatively, it was possible to disassembly the unit and bake out the components individually at higher temperatures.

If the outgassing rate of the FGS was not sufficiently reduced by the components bakeouts, then molecular absorbers could be installed to further reduce the outgassing rate. An interior model of the FGS, using molecular transport kinetics modeling would be used to determine the optimal locations of the absorbers.

After the electronics boxes were deintegrated from the FGS and baked out, it became apparent that the electronics boxes did not account for enough of the contamination to bring the FGS within its requirement, and that the absorbers could not make up the difference. As a result the remaining part of the FGS has to be baked out.

3 Baseline measurement

The outgassing rate of the FGS was measured in a chamber set-up consisting of a support fixture called Star Selector Test Stand (SSTS). Because the decay constant was not measurable over the short duration of the bakeout, data from previous spacecraft were used to estimate the time required to bake out the FGS to the requirement

4 Component bakeout

Contamination reduction began with measurement and bakeout of FGS components. The FGS was separated in two sections, the dome and the Bench. Most of the electronics are mounted on the Dome; two remote units and one sensors electronics assembly were deintegrated from the dome. The bench was disassembled in layers; first the top and side blankets and exostructure panels, then the interior blankets and heaters panels, finally the image dissector camera assembly and electronics. Whenever possible, cables were left mated in place to minimize the need for new staking compounds.

The outgassing of the individual was determined on a total grams per second basis by using a test box. Assuming that the sticking coefficient is unity, the total outgassing may be calculated from the relationship:

$$OGR = \Delta f \sigma (A_{QCM} + A_{vent})(\frac{1}{3600})$$

Where the outgassing rate (OGR) is in grams per second, Δf is the QCM reading in Hz/hr, σ is the QCM sensitivity in g/cm^2/Hz, A_{qcm} and A_{vent} are the QCM crystal and test box vent areas measured in cm^2, and the final factor converts hours to seconds. The measurement made allowed to make prediction of the outgassing rate of the reassembled FGS.

Although the post bakeout outgassing rates for the components were lowered by as much as two orders of magnitude, the remaining contaminations sources in the FGS bench and dome were sufficient to prevent the FGS from the second servicing mission requirement.

5 Adsorbers implementation

To reduce the FGS outgassing beyond the level achieved by the component bakeout, molecular adsorbers was planned. Molecular adsorbers are ceramic materials with a very large surface are to volume ratio. The adsorber, Linde 13x, is bonded to a corderite honeycomb substrate to increase the presented surface area. These substrates are bolted to the flight hardware.

Some of the component were no longer needed on the FGS and were modified to provide mounting sites for molecular adsorbers. The optics and electronics in these items were removed. The stud and mounting plates for the adsorbers were certificated separately. A total of 49 adsorbers were mounted inside the FGS.

6 Bench bakeout

The component bakeouts eliminated about 45% of the FGS outgassing; however, the mission requirement is 4% of the initial outgassing rate. Therefore, despite risks to the hardware, the bench and dome were baked out.

The bakeout of the bench occurred in a 25 foot diameter, 60 ft tall vacuum chamber at Goddard Space Flight Center. To measure the total outgassing of the bench it was necessary to create a test box large enough to enclose the bench associated. To minimize the schedule impact, the bench was baked out at the highest acceptable temperature, acceptable being defined by the trade off between schedule risk and hardware risk. At the beginning of the bakeout, the relationship between the outgassing rate at the bakeout temperature (29.5° C) and the certification temperature (25° C) was noted. Having established a goal for certification, it was possible to estimate how close to certification the cench was by monitoring the outgassing rate as 29.5° C. The outgassing data was analyzed to determine the decay constant, and predictions of the time required to reach certification were made. Ideal outgassing behaves according to and exponential decay process, with the outgassing rate given by:

$$OGR_t = (OGR_{initial})e^{-t/\tau}$$

The outgassing rate (OGR) is usually given in grams per second, t is the time and τ is the decay constant. With a single outgassing specie, the decay constant does not change with time. Because the outgassing sources contained a mixture of species the composite decay curve of the form:

$$OGR = Ae^{-t/_{A\tau}} + Be^{-t/_{B\tau}} + \cdots + Je^{-t/_{J\tau}}$$

After 200 hours the composite decay constant was stabilizing around 321 hours, a number which would result in the bakeout criteria being met several weeks past the lasts acceptable end date.

When it became apparent the that the bench would not meet the certification in the time allotted, the FGS temperature was slowly raised above the safe limit. Near the end of the bakeout the temperature was lowered to 25° C to verify the outgassing rate relationship. The bakeout was concluded on time, with the bench meeting the certification goals.

7 Final Cleanliness measurement

The FGS outgassing certification occurred in the same test set-up as the initial outgassing measurement. A 48 hr bakeout phase at 29° C was conducted to remove any surface contamination. The FGS temperature was reduced to 25° C for certification. On a -65° C QCM, the FSG front aperture outgassing rate was 1.61×10^{-8} g/s, and the aft vent was 1.0×10^{-8} g/s. Then, the FGS was dropped to 21 ° C and measured on -88° C QCM. The front aperture outgassing rate was 1.1×10^{-8} g/s. This rate was within 3% of the prediction , and was well within the requirement.

8 Conclusion

It is possible to retroactively implement more stringent contamination requirements upon an instruments or spacecraft. Many portions may be easily deintegrated for high temperature bakeout, and the remainder may be backed out close to its maximum temperature by using temperature control zones and real time analysis of the bakeout progress. The addition of molecular adsorbers wherever feasible will also reduce contamination levels. The HST spare Fine guidance sensor outgassing rate was reduced by more than an order of magnitude using these methods.