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KOMPSAT-2 Particulate Contamination Analysis

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Abstract

The present analysis quantifies the particulate contamination of KOMPSAT-2 satellite until in orbit life. Assumptions are defined about integration and test conditions and durations, then a budget is drawn.

As KOMPSAT-2 activities are carried out in good cleanliness conditions, the particulate contamination budgets for satellite and instrument surfaces at BOL is fair. To summarise, in the baseline launch conditions (class 10,000), the contribution of satellite AIT and launch activities adds 500 PPM to MSC and STA apertures (telescope mirrors ; front lens ; baffle), 20 000 PPM to MSC and STA outer surfaces, 14 000 PPM to plate-form horizontal surfaces, 1400 PPM to plate-form vertical surfaces, 1000 PPM to plate-form radiators and less than 300 PPM to solar arra

초 록

본 연구는 임무완성기간까지 다목적실용위성 2호기의 각 표면에 축적되는 입자오염량을 분석한 것이다. 이를 위하여 위성체의 조립 및 시험 기간 및 환경조건을 가정하였다.

본문에서 보여지는바와 같이 다목적실용위성2호의 조립 및 시험이 잘 관리되어지는 조건에서 수행된다면, 위성체의 각 표면에 축적되는 입자 오염량은 적정한 수준내로 관리 될 수 있다.

10,000 class의 발사장 환경을 기준으로 할때, AIT와 발사장에서의 조립 및 시험으로 인해 MSC 및 STA의 내구경에는 500PPM, 외부 표면에는 20000PPM, 위성체의 수평면에는 14000PPM, 수직면에는 1400PPM, radiator에는 1000PPM 및 solar array에는 300PPM의 입자오염량이 축적될것으로 예상된다.

키워드 : 다목적실용위성2호(KOMPSAT-2), 입자(particulate), 오염(contamination), 광학(optics), 청정도(cleanliness), 세척(cleaning)

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1. Introduction

The present analysis quantifies the particulate contamination of KOMPSAT-2 satellite until in orbit life. Assumptions are defined on integration and test conditions and durations, then a budget is drawn.

The cleanliness is a key factor in instrument performance, particularly for optical equipment, sensitive to molecular and particulate contamination. With optical systems, the contamination degrades both radiometric sensitivity and image quality, and the impact strongly depends on system wavelength. With thermal surfaces, the solar absorption and the emissivity are changed.

During manufacturing, integration and tests phases, and then in orbit, contaminants are depositing on all surfaces and could degrade the performances of the instrument. The least risky way to achieve a low level of contamination is to think clean from the beginning, about the instrument design, its fabrication processes and its test conditions, thereby eliminating many sources of uncertainty and risk.

2. Particulate Contamination Analysis

2.1 Sensitive Items and Contamination Sources

2.1.1 K2 Contamination Sensitive Items

The contamination most sensitive parts of KOMPSAT-2 are the optics and baffle of MSC and of STA.

Then, the other contamination sensitive parts of KOMPSAT-2 are :

- Solar array cells
- Solar array sun sensors
- MLI
- Radiators (SSM)
- Mechanisms (solar arrays, antennas)
- Radio-frequency devices and wave guides
- Propulsion pipes and thrusters

The 3 last elements have their own protections (by design, or thanks to removable covers used during AIT) assessed to be sufficient and their case will not be further addressedin present analysis. Standard cleanliness practice allows to avoid trouble with these devices.

The internal contamination of MSC and STA sub-assemblies is not addressed here, only the particulate contamination at MSC and STA apertures will be budgeted, from exposure to AIT and launch environment when cover is off. From [RD4] and [RD5] documents, the contamination status at instrument delivery to K2 team is given in the following table

Table 1. contamination status at delivery

Contamination at delivery	Particulate Level (PPM)	Molecular Level (g/cm2)
MSC inner surface	300	5x10-7
MSC outer surface	1000	1x10-6
STA inner surface	500	4x10-7

2.1.2 K2 Contamination Sources

The environment during manufacturing, assembly, test and launch, is source of molecular and particulate contamination. The contribution of environment taken into account in present analysis is based on the particles deposition rates given in standards [RD1 to RD3] or measured at Astrium.

Spacecrafts have moreover internal sources of molecular contamination, i.e. organic materials which out-gas in vacuum during spacecraft vacuum test

and in orbit, but internal sources of particles are neglected. Indeed, the rules for spacecraft design forbid the use of particles generating materials. Nevertheless, there is a possibility of particles redistribution during mechanical perturbations : vibration and acoustic tests, transportation, launch, which is here after also accounted for.

2.1.2.1 Molecular Contamination

Two types of molecular contamination causes can be identified: the direct contamination by contact and the indirect contamination by gas condensation.

The contamination by direct contact occurs during manufacturing and AIT, for example when glues, adhesive tapes, machine oils, machine lubricants, detergents are used, and when bad handling with naked hands or dirty gloves occurs. This kind of contamination is considered as hazardous and has to be avoided, following good practice and specification of PA plan and AIT procedures. Note also that not pure cleaning liquids would let contamination residue on surfaces after a cleaning tentative.

The contamination from gas condensation is an indirect source of contamination. The off-gassing and out-gassing sources can be within the flight hardware, or in the manufacturing and AIT equipment and environment. For example, packing materials, structure resins, glues, paints, varnishes, adhesive tapes, solder fluxes, oil from vacuum pump, test equipment bays are potential sources of contamination.

The molecular contamination from gaseous species results from the condensation of molecules on surfaces, under clusters or layers. They stick to the substrate under Van der Waals force or hydrogen link. The residence time depends on species and is extremely temperature dependent. The resulting thickness is in the range of 0.1 nm to about 1m. The molecular contamination is expressed in surface mass (mg/m2).

2.1.2.2 Particulate Contamination

The particulate contamination is an accumulation of solid particles (organic and inorganic) falling on surfaces or attracted by electrostatic forces. The big particles fall down easily under gravity, while the smallest (sub-micron size) undergo a brownian movement until they hit and stick to a surface. The particles stick to the surface they hit under electrical forces. The common size range of concern is from 1 m to 1 mm.

Knowing that the air conditioning system of clean rooms includes HEPA filters, which filter down to 0.3 m, the main source of particulate contamination is the working personnel. Thus, the main particulate contaminants are the following:

- Human dead skin cells, hair cosmetics
- Fibres and lint from clothing, dust carried in on clothes and shoes
- Particles from machining, flakes from paints and coatings

Particles are also released during launch by the launcher fairing because of vibration.

2.1.3 Contamination Effect

The contaminant deposits modify all surface properties and mainly reduce the optical ones. Both molecular and particulate contamination types result in increase of light absorption and light scattering. As a consequence, the thermal properties of the surfaces are also degraded.

About light absorption, the molecular contami -nation can be characterized by an absorption coefficient, which depends on the wavelength, the incident angle and the type of contaminant. The particles are considered to act by pure obstruction, i.e. by total absorption, proportional to their surface ratio expressed in PPM.

About light scattering, the molecular contami -nation can be characterized by a BRDF or a BTDF, which depend on the wavelength, the incident

angle and the type of contaminant. Few data are available and come from measurement on samples. The particles are considered to act by pure obstruction and their scattering effect can be easily modelled using scattering dedicated software.

The increase of both absorption and scattering leads to a loss of optics useful transmittance. The increase of scattering also leads to an increase of stray light, resulting at system level in SNR degradation, or in a degradation of image quality, generally expressed by the MTF. The impacts of both absorption and scattering are of concern for optics operating over visible light, and furthermore UV light, while transmittance loss is generally the main concern over IR spectral area (less scattering than with visible light), according to the -2dependence of Mie theory if particles size is of wavelength order.

2.2 Contamination Control

2.2.1 Contamination Qualification

The molecular contamination is quantified in g/cm or mg/m (10-7g/cm=1mg/m), using witness samples exposed together with the hardware and measured by IR spectroscopy, or hardware sampling by wipe test then measurement by IR spectroscopy.

The particulate contamination can be divided into 2 classes regarding the control methodology:

- Particle per volume
- Particle per surface area

The volume contamination applies to ambient air and is easily monitored via airborne particles counters, which use the scattering of laser diode light by the particles in an air flow vacuumed by the counter. Refer also to [RD1].

The particulate contamination of surfaces is expressed by an obstruction ratio in PPM, which is the ratio between the cumulated area covered by the particles and the area of the considered surface (for example, 10 000 PPM means 1 % obstruction). It can be quantified using particles fall-out witness samples (PFO) exposed together with the hardware and measured with a dedicated mean, a "PFO-meter"operating like airborne particles counters or microscope counting. It can also be quantified from hardware sampling by tape-lift test then microscope counting. Refer also to [RD2].

2.2.2 Visual Inspection

A visual inspection of the accessible surfaces has to be performed at AIT key points and reviews (test readiness review, test result review), at instrument and spacecraft delivery and in case of cleanliness anomaly. Visual inspections have to be performed by a quality agent, plus the cleanliness engineer if needed. Visual inspections are performed by trained people with naked eyes, using both white source and UV source, to better detect dust and organic stain. The sensitivity of naked eyes is about 300 PPM and 10 mg/m. Visible particles, stains of rust and oxidation, brazing flux, stains of glue, paint or grease, tape residue and fingerprints are cleanliness anomalies.

2.2.3 Possible Corrective Action

The following points could allow to recover the budgets when allocations are violated. The list is rather exhaustive and the proposed ideas have very different feasibilities and impacts. During AIT phase, any modification will have to be discussed in the frame of a MRB.

- To minimize the number of personnel in working areas
- To tighten the personnel garment
- To use more often covers, housing and protective films
- To shorten AIT activities

- To inspect closer and more often
- To monitor closer, to measure witness samples more often
- To apply cleaning

2.2.4 Cleaning

A cleaning process has to take into account the size, the access, the scratch sensitivity and the chemical sensitivity of the hardware surface. Any not systematic cleaning would have to be ordered as a corrective action in the frame of a MRB following hazardous contamination.

For particles cleaning, the vacuum cleaner is only efficient against biggest particles. Air blowing is more efficient and could be applied via an ionised gun, but particles can deposit away on the space hardware.

After particles cleaning, the basic cleaning process generally applied against molecular contamination is the hand wiping using dedicated wipes with low level of extractable non-volatile residues and particles and using high purity soft solvents with very low NVR like isopropyl alcohol (IPA) or ethanol. In any case, the purity of solvent is of major importance and a high purity grade is needed, like 99.8 % with Prolabo Normapur alcohol. The compatibility of solvent with surface material has to be checked on samples prior to application. The wipe has also to be particles free, like Texwipe Alpha 1010 or lens tissue.

Care shall be taken with the mat black paints of optical baffles. Wipe cleaning is normally forbidden on such surfaces with high roughness, not to degrade the surface nor spread pollution.

2.3 Particulate Contamination Analysis

2.3.1 AIT Task Duration and Condition

The analysis is based on data from K2 AIT flow chart, which defines the conditions and durations of activities, shown in Table 2. The clean class is taken into account in the budget, refer to the next section for the assumption on contamination rate. It is to be noted that K2 activities are carried out in quite good cleanliness conditions, as class 100,000 is generally considered at satellite level in space industry.

The main instrument MSC and the star tracker STA have a cover during the most parts of AIT activities. For mechanical test, the covers may be replaced with tapped films. For alignment check, and potential performance check, MSC and STA are supposed to be exposed only few hours to the working environment. Twice one working day is accounted for (one for alignment measurement and one for final alignment measurement), together with a provision for cover handling, which is rounded to the amount of 100 PPM.

According to usual AIT activities, the following equipment units are supposed to be mounted only for part of the AIT sequence :

- The plate-form MLI could be only mounted for TV test, vibration test, EMC test and mass properties measurement and stored flat and protected at the other AIT steps and definitely mounted at launch pad. But the analysis is carried out for the worst case where MLI is always kept in place on the bus.
- The MLI of MSC and STA units are not dismounted since the delivery of MSC and STA to the satellite team.
- The radiator SSM are mounted on the plate-form walls from the beginning, but protected with a film, except for TV test, vibration test, EMC testand mass properties measurement.
- The SA is mounted only for vibration test and remains folded. It can be cleaned at launch pad and the cleaning is supposed to zero the contamination of the cover-glasses. For assessment, the worst case with no cleaning is taken into account.

Table 2. AIT tasks flow chart with duration and cleanliness condition

Main Activity	Duration (day) (Include non-working days)	Clean class	Plate-form MLI	SSM protec film	SA	MSC protec cover	STA protec cover	Comment
Mechanical Build-Up	100	5000	off	on	off	on	on	
Electrical Test (1 st)	70	5000	off	on	off	on	on	
Alignment Measurement	20	5000	off	on	off	on	on	MSC-STA are open over few hours for alignment check
Thermal Vacuum Test	50	5000	**on**	**off**	off	**off**	**off**	
Vibration Test	45	5000	**on**	**off**	**on**	on	on	MSC-STA covers may be replaced by tapped film
Electrical Test (2nd) & 1 st Motion Test	65	5000	**on**	on	**on**	on	on	
EMI/EMC Test	20	100000	**on**	**off**	**on**	on	on	MSC-STA covers may be replaced by tapped film
F nal Alignm ent Measurement	10	5000	**on**	on	**on**	on	on	MSC-STA are open over few hours for alignment check
Mass Property Measurement	20	5000	**on**	on	**on**	on	on	MSC-STA covers may be replaced by tapped film
Reserve period	35	5000	**on**	on	**on**	on	on	
Packing and storage in container	0	10000	**on**	on	**on**	on	on	
Delivery	5	10000	**on**	on	**on**	on	on	
SIM Test	20	10000	**on**	on	**on**	on	on	
Final Mechanical Build-Up (Include MLI activity)	20	10000	**on**	on	**on**	on	on	
Fueling	8	10000	**on**	on	**on**	on	on	
Fairing	5	10000	**on**	**off**	**on**	**off**	**off**	
Assemble to Launch Vehicle, baseline	10	10000	**on**	**off**	**on**	**off**	**off**	
Assemble to Launch Vehicle, worst case	10	100000	**on**	**off**	**on**	**off**	**off**	

2.3.2 Assumption for Analysis

To draw the budgets, the following assumptions are taken into account about environmental effect :

- 4 hours under class N environment as per [RD1] induces a particulate load PFO = 0.069 * N0.072, expressed in PPM as shown in the Table 3. In fact, this worst case concerns the upward side of horizontal surfaces. In the same environment, the particulate contamina -tion of vertical surfaces is 10 times lower and those of downward horizontal surfaces is 100 times lower, stated from measurement. The here above particulate contamination rate formula concerns clean rooms under activity, as the air conditioning system of clean rooms is able to provide much cleaner air, and very clean level is observed in clean rooms without human activity.
- A cover brings 100 % efficiency against particulate contamination, and 100 PPM is taken into account for cover handling over the whole AIT phase. During vibration and acoustic tests, mass properties measure -ment, EMC test, it is assumed that the covers are removed and that a film in clean allowed plastic material is taped at instrument aperture, with the same contamination protection efficiency as with a cover.
- Without cover, the protection factor of optics brought by the cavity built with baffle and structure is assumed to be 0.5. It means that

the particulate contamination rate of a lens or mirror into an instrument or behind a baffle is assumed to be half the rate of the same component alone straight exposed to ambient conditions. When folded, the particulate contamination rate of solar arrays is assumed to be divided by 5.

- The launch campaign, during preparation and under fairing, is under class 10 000 (baseline) or 100,000 environment (worst case).
- The duration considered under fairing before launch, without any coverage, is 10 days baseline.
- Particles may be flown away and redistributed during vacuum test (at refilling), vibration and acoustic tests, transportation and launch ascent. 20PPM is taken into account for vacuum test, 20PPM during vibration test and acoustic test, 0PPM during EMC test, 10PPM during transportation, 50PPM during launch. These data areapplied whatever the surface orientation is.

Table 3. Accumulated contaminant quantity under various environment

Environment class (as per FED-STD-209)	Surface obscuration over 24h for horizontal upward surface (in PPM) PFO = 0.069*C^0.72
100	2
200	3
500	6
1000	10
2000	16
5000	32
10000	52
20000	86
50000	167
100000	275
1000000	1442

2.3.3 Analysis Result

The BOL budget is drawn in Table 5 for the baseline and worst cases of launch pad cleanliness class.

Note that the major contributors to particulate contamination are :

- the EMC test and the launch campaign for plate-form surfaces ;
- the launch campaign for MSC and STA inner surfaces ;
- the mechanical and electrical AIT and the EMC test for MSC and STA outer surfaces.

The Table 4 summarise the budget about satellite AIT phase and add it to the status at unit delivery.

Table 4. Contaminant budget per each milestone

Particulate contamination level	At unit delivery (in PPM)	At BOL baseline (in PPM)	At BOL worst case (in PPM)
MSC telescope mirrors and baffle	300	300 + 500	300 + 1700
MSC outer surfaces (horizontal)	1000	1000 + 20000	1000 + 23000
STA front lens and baffle	500	500 + 500	500 + 1700
Satellite MLI (horizontal)	0	14000	17000
Satellite radiators SSM	0	1000	1300
Solar array cover-glasses	0	300	350

The values are rounded with respect to Table 5 and the worst case is given under brackets, when significant. Note that, as explained in section 2.3.2, the vertical surface have a particulate contamination level 10 times lower than the horizontal surfaces upward.

As per section 2.2.1, 1000 PPM particulate level on satellite radiators SSM means 0.1 % absorption, thus a negligible increase of solar absorption , which reaches 2.3 % on MSC outer surfaces horizontal upward in the worst case.

Table 5. Contamination analysis results

Cumulated particulate contamination level (in PPM)	Surface					
Main Activity	MSC and STA MLI	Plate-form MLI	SSM	SA cover glass	MSC mirror and baffle	STA front lens and baffle
Mechanical Build-Up	3178	0	0	NA	0	0
Electrical Test (1st)	2224	0	0	NA	0	0
Alignment Measurement	636	0	0	NA	0	0
Thermal Vacuum Test	20	20	20	NA	20	20
Vibration Test	1450	1450	163	29	20	20
Electrical Test (2nd) & 1st Motion Test	2065	2065	0	41	0	0
EMI/EMC Test	5494	5494	549	110	0	0
Final Alignment Measurement	318	318	0	6	0	0
Mass Property Measurement	636	636	64	13	0	0
Reserve period	1112	1112	0	22	0	0
Packing and storage in container	0	0	0	0	0	0
Delivery	262	262	0	5	5	5
SIM Test	1047	1047	0	21	0	0
Final Mechanical Build-Up (Include MLI activity)	1047	1047	105	21	0	0
Fueling	419	419	42	8	0	0
Fairing	262	262	26	5	131	131
Assemble to Launch Vehicle, baseline	523	523	52	10	262	262
Assemble to Launch Vehicle, worst case	2747	2747	275	55	1373	1373
Launch ascent	50	50	50	10	50	50
Cumulation at BOL, baseline case	**20692**	**14654**	**1021**	**292**	**538**	**538**
Cumulation at BOL, worst case	**22915**	**16878**	**1243**	**337**	**1649**	**1649**

Assumptions	
Particles redistribution during thermal vacuum test	20 PPM
Particles redistribution during vibration test	20 PPM
Particles redistribution during satellite transportation	10 PPM
Particles redistribution during launch ascent	50 PPM
Particulate contamination at MSC-STA aperture due to cover handling and alignment check (cumulation)	100 PPM
Optics protection factor within instrument	0.5
SA protection factor when SA is folded	0.2

The MLI of MSC and STA is not dismounted since delivery to satellite team
The plate-form MLI is supposed to be mounted for TV test, EMC test and vibration test, stored protected
The radiators SSM are supposed to be protected with a film, but for TV test, EMC test and vibration test

3. Conclusion

As K2 activities are carried out in good cleanliness conditions, the particulate contamination budgets for satellite and instrument surfaces at BOL is fair.

To summarise, in the baseline launch conditions (class 10 000), the contribution of satellite AIT and launch activities adds 500 PPM to MSC and STA apertures (telescope mirrors ; front lens ; baffle), 20 000 PPM to MSC and STA outer surfaces, 14 000 PPM to plate-form horizontal surfaces, 1400 PPM to plate-form vertical surfaces, 1000 PPM to plate-form radiators and less than 300 PPM to solar array.

In the worst case launch conditions (class 100 000), the contribution of satellite AIT and launch activities adds 1700 PPM to MSC and STA apertures (telescope mirrors ; front lens ; baffle), 23 000PPM to MSC and STA outer surfaces, 17 000 PPM to plate-form horizontal surfaces, 1700 PPM to plate-form vertical surfaces, 1300 PPM to plate-form radiators and less than 350 PPM to solar array.

Reference Document

1. FED-STD-209 E, Clean room and clean work station requirements.
   (now replaced by ISO 14 644 standard)
2. MIL-SDT-1246 C, Product cleanliness levels & contamination control.
3. PSS-01-201, Contamination and cleanliness control.
4. MSC analysis from ELOP.
5. LXO.SP.0011.MMS-T iss.1, Leostar Star Tracker technical specification.