STATUS OF XMM TEST PROGRAMME IN CSL EUV AND X-RAY TEST FACILITY (FOCAL X)

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The X-ray Multi Mirror Mission (XMM) is the second « Cornerstone » project in the ESA Long Term Programme for Space Science. Capabilities of the XMM dedicated optical test facility, named FOCAL X, are recalled after a short historical summary. The presented topics are : vacuum chambers, optical beams (EUV, visible and X-ray), detectors, cleanrooms, handling tools, characteristics of acceptable test articles,…

The flexible design is underlined and examples of additional tests, not foreseen at the beginning of the project, are given : X-Ray Baffle integration testing, Reflection Grating Assembly mask illumination test, alignment lens crosshair lateral position determination,... Another proof of the facility flexibility is its modular design : each of the three measuring channels could be used independently from the others and the chamber size could be modified, in function of the test article requirements.

An overview of the present XMM test status at CSL is given, comprising a summary of the total test duration up to now and the future test time for the next activities. A "learning curve" analysis is presented, showing the increasing data volume obtained in a reference testing time.

CSL, one of the four co-ordinated ESA facilities, houses vibration, thermal and optical test facilities that have been used for the XMM Mirror Modules. Using the test capabilities gathered at CSL has many advantages. By reducing the number of transports, it was possible to save time and money. The handling activities have also been reduced and the risk associated to this type of activities was decreased. The potential contamination inherent to handling was also minimised. An estimate of the various savings is also provided.

XMM is a critical project from contamination point of view, both for particulate and molecular aspects. Evolution of the cleanliness level of the cleanrooms and of the test facilities is reported, in parallel with the cleaning strategy and its evolution since the beginning of the project.

A powerful available facility, controlled by a trained team, has been presented. All this expertise and test equipment represent an asset for future scientific space programmes. Small adaptations are sufficient to make it the ideal optical facility for next generation optical payloads testing.

Keywords : X-ray optics, XMM, EUV and X-ray test facility

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1 Introduction

The spaceborne observatory XMM (X-ray Multi-Mirror) satellite is the second “cornerstone” project of the ESA Horizon 2000 Science Programme. XMM has been designed to perform high throughput X-ray spectroscopy over a broad energy range (0.1 keV to 12 keV). The payload consists of three telescopes and scientific instruments. The satellite, after in-orbit deployment, is 10 m long by 16 m wide, its mass at launch is 3900 kg.

This paper will focus on the tests of the X-ray optics of the telescopes called Mirror Module (MM) at the Centre Spatial de Liège (CSL). Each MM is a grazing incidence Wolter-1 type telescope. Its main characteristics are given in table 1. A MM consists of 58 highly nested mirror shells (MS) bonded at one end on a spider and their mechanical interface structure. The main MS characteristics are given in table 2. The telescope, MS and MM designs are detailed in ref. 1,2,3,4.

TABLE 1 : MM Characteristics.

Focal length	7500 mm
Field of view	15 arcmin
HEW FWHM	< 16 arcsec (0.1-12 keV) 8 arcsec (0.1-12 keV)
Effective area	1475 cm² at 1.5 keV 580 cm² at 8 keV 130 cm² at 12 keV
Weight	420 kg

TABLE 2 : MS Characteristics.

Focal length	7500 mm
Outermost diameter Innermost diameter	700 mm 306 mm
Thickness	from 0.47 to 1.07 mm
Length	600 mm
Number of MS per MM	58
Reflective surface	2500Å gold layer

Up to now, one QM MM, three STM MMs (only vibration test for STM) and four FM MMs have been submitted to thermal, vibration and optical tests at CSL. The test results are reported among others in ref. 5, 6, 7, 8. Thermal and vibration tests, although difficult to perform, are classical activities for CSL. For the optical test, a totally new facility had to be built in order to meet the XMM requirements. This paper presents briefly this facility, called FOCAL X, its evolution since the beginning and gives an overview of its capabilities. The facility is fully described in ref. 9, 10, 11.

2 FOCAL X facility

2.1 Historical record

A short chronological list of events seen from CSL point of view is given hereafter :

September 93 : first contacts between ESA and CSL about a vertical EUV and X-ray test facility.

December 93 : Decision to perform an horizontal EUV test in order to validate the concept of an EUV optical test of XMM X-ray optics.

May 94 : CSL proposal for the development of a vertical facility for testing the XMM Mirrors.

The only facility existing in Europe at that time to test XMM mirrors was the horizontal PANTER facility in Neuried (Munich). It is able, using an X-ray source located at about 130 m from the optics, to illuminate in a slightly divergent beam, the full aperture of an XMM MM. Nevertheless, this method suffers two drawbacks :

- the first 100 mm of the shells are not correctly illuminated because of vignetting effect and non-nominal reflection caused by the beam divergence,
- because of the horizontal set-up, gravity affects the shape of the optics and of their mechanical support to be tested. The gravity effects are minimised in a vertical configuration.

The realisation of a vertical optical test facility using an EUV collimated beam covering the full XMM aperture and partial X-ray beams is decided. This facility is complementing the PANTER test facility. History showed that, with the huge number of tests required by XMM, the two facilities have been intensively used during all the XMM test period.

June 94 : Kick-off meeting for the Vertical Test Facility development.

July 94 : Digging works are started. To house the facility, a new building is necessary. The building construction and the activities linked to the test facility itself were run in parallel. Moreover, the horizontal test set-up is used to acquire knowledge and debug as much as possible in advance the EUV vertical channel. Lessons learnt thanks to this test were implemented immediately in the design of the vertical facility.

October 94 : Seismic block installation (see picture 1).

PICTURE 1 : Seismic block installation.

PICTURE 2 : Main chamber introduction.

December 94 : The horizontal test is completed successfully but the set-up is maintained operational in order to perform subsystem tests of the EUV source (after servicing and adaptation), the EUV filters, the CCD cameras. The tightness of the building is reached. The pumping systems with valves and pressure gauges are delivered at CSL.

April 95 : Vacuum chamber introduction in the building trough the roof (see picture 2)

From September 95 to February 96 : Integration of mechanisms, detectors (3) and sources (3), integration and alignment of EUV collimator, integration of X-ray collimator, cleanrooms implementation. The shaker is also upgraded and installed in class 10 000 cleanroom to meet the XMM vibration test requirements. The vibration test adapter is designed with the help of LTAS (Laboratoire des Techniques Aéronautiques et Spatiales - Liège University) for the finite element analysis. Finally, facility acceptance tests are carried out with the XMM DM2 MM.

From March to August 96 : QM tests are performed. They are reported in ref. 5. They consist in optical, vibration, thermal and opto-thermal sequences.

From September 96 to January 97 : Vibration tests of Structural/Thermal models with and without Reflexion Grating Assembly are performed. In parallel, facility improvements and calibration measurements are run.

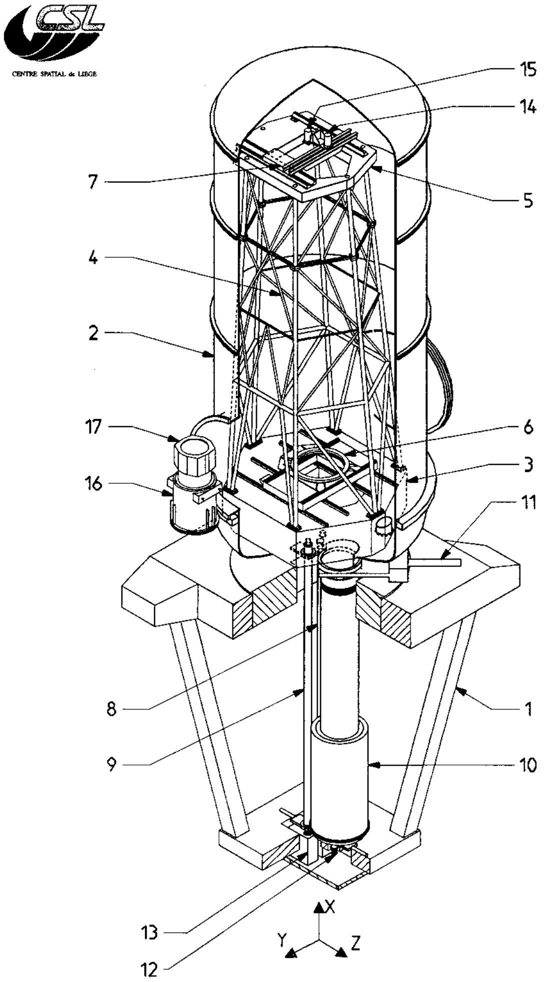
From February 97 to June 97 : environmental tests (optical, vibration, thermal) of FM1 and FM2 MMs are taking place.

From July 97 up to now : FM3 and FM4 MMs environmental tests, XRB test sequences for QM, FM1, FM2, FM3 and FM4, RGA1 and RGA2 test campaigns with FM1 and FM2, FM3 MMs are performed. The final flight configuration of FM3MM+RGA2 is also tested.

2.2 Technical description

The facility is described in details in [10, 12, 13] . The main features are summarised hereafter and shown on figure 1 and on picture 3. The overall height of the facility is 30 m. Six vacuum chambers are composing the facility. The main one is 12 m high and has a diameter of 4.5 m. The other ones are housing the three sources and the two collimators. The total volume to evacuate is about 200 m³. 23 pumps are necessary to ensure a working pressure of about 10^{-6} mbar in the main chamber in a reasonable time (between 3 and 4 hours). Three optical beams are available and their main characteristics are given in table 3.

FIGURE 1 : FOCAL X schematic view.



1. Seismic block, 2. Vacuum vessel, 3. Optical bench, 4. Tower, 5. Detector optical bench, 6. Specimen mechanisms, 7. Detectors mechanisms, 8. X collimated beam, 9. X pencil beam, 10. EUV channel, 11. Valve, 12. EUV source, 13. X-ray sources, 14. EUV detector, 15. X-ray detectors, 16. MASP, 17. Telescope

PICTURE 3 : FOCAL X main vacuum chamber.

Looking towards the facility from the class 10 000 cleanroom area during a typical alignment sequence.

The test article is placed on an adapter (MASP) inside the main vacuum chamber, on a 5-axis motion system : 2 lateral translations, 1 rotation around vertical axis, 2 tilts around horizontal axes. Using this capability, the test article can be accurately moved in front of each of the three beams. To record the different signals, 3 detectors are available at the focal plane level on a high precision 3-axis translation system. The detectors main characteristics are given in the table 4.

The three detectors can be used with each of the beams. In order to simulate a far off-axis source, it is possible to tilt the whole optical bench and detectors support structure from – 2 to 7.5 degrees.

TABLE 3 : Beam main characteristics.

Beam name	**EUV beam**	**X1 channel**	**X2 channel**
Size and shape	Disk of 800 mm outer diameter, internal obstruction of 250 mm	Pencil beam of 0.5 mm diameter at specimen entrance level	Banana shape (about 8*50 mm²)
Source(s) & fluxes	1. EUV Electron Cyclotron Resonance Helium source 8 10^{15}ph/s*sr@58.4 nm 1 10^{15}ph/s*sr@30.4 nm. 2. Laser @ 633 nm.	Open source with various targets (Aluminium, Copper, Gold, Molybdenum, Carbon) 1.44 10^{12} ph/sec*sr	Open source with various targets (Aluminium, Copper, Gold, Molybdenum, Carbon) 1.44 10^{12} ph/sec*sr
Filterwheel	Not Applicable	16 positions with various filters : Aluminium, Copper, Beryllium, Nickel, hole, shutter	16 positions with various filters : Aluminium, Copper, Beryllium, Nickel, hole, shutter
Optics	Cassegrain collimator < 2 arcsec divergence	Two 0.3 mm pinholes about 8 arcsec half-angle divergence	Off-axis Zerodur parabolic gold coated mirror divergence : a few arcsec
Working wavelengths	30.4nm, 58.4 nm, 633 nm, visible continuum	From 1 keV to 13 keV	From 1 keV to 13 keV

TABLE 4 : Detectors main characteristics.

Detector name	**EUV CCD**	**X-ray CCD**	**Solid State Detector**
Type	Thinned back illuminated CCD	Front illuminated CCD	Germanium solid state detector
Active area	about 26*18 mm²	about 26*18 mm²	25.5 mm diameter
Pixel size	22.5*22.5 µm²	22.5*22.5 µm²	Not applicable
Window / Shutter	Shutter	Shutter	Beryllium, 13 µm thick with hexagonal mesh
Filter- and Slit- wheel	Various EUV and visible filters (30.4 nm, 58.4 nm, 420nm, 610 nm)	Not Applicable	Wheel with hole, shutter, slits, calibration source
Operating temperature	- 100°C	- 100°C	- 150°C
Cooling system	LN2 cold plate and heaters inside camera head	LN2 cold plate and heaters inside camera head	Home-made dedicated LN2 cooling system

FOCAL X is located in a 28*18*15 m³ class 10000 cleanroom and a dedicated class 100 has been built around the chamber. Cleanrooms capabilities are detailed in paragraph 5 and a schematic is given at figure 9. A 10-ton crane is installed in the class 10 000 area. In the class 100 areaa, a 2-ton crane and a two-axis robot are available.

The facility has been designed to accept different types of XMM test articles :

- single mirror shell on a rigid interface
- single mirror shell hanging on the suspension device[1]
- bare mirror module
- mirror module equipped with an XRB, an RGA and an EXB.

In the present status, the acceptable article can weigh up to 800 kg. The envelope is approximately a cylinder of 0.8 m diameter and 2 m height but this could be easily extended.

[1] A suspension device is an ingenious system especially designed for single mirror shell handling. It basically consists of 16 actively controlled hooks and springs holding the MS with as little stress as possible in an adjustable position in height and in tilt.

2.3 Modular design

Each of the three channels can be used independently from the other ones. This allows :

- maintenance in parallel with testing
- saving of time and money by reducing pumping system use
- upgrade in parallel with testing

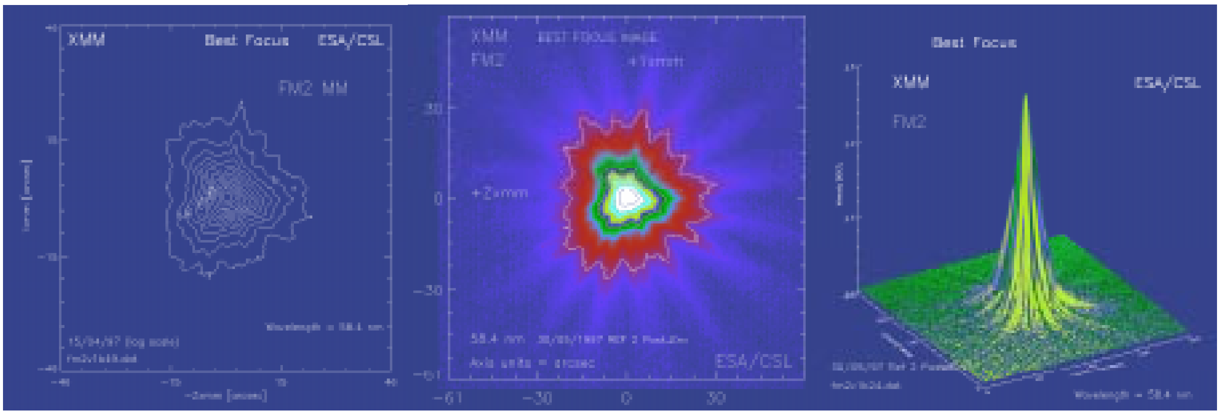
All the detectors have also their own independent cooling and power supply system so repair and maintenance activities on one detector is compatible with testing with the other ones. This is a very useful feature to optimise a schedule.

The main chamber is about 12 m. high and comprises three parts. The top two parts can be removed and so a smaller chamber, quicker and cheaper to operate can be made available, tailored for smaller test articles.

2.4 Typical results

Some typical results are shown hereafter : a typical EUV image in 2D and 3D representations, an X-ray scanning over some Mirror Shells allowing metrology measurements, X-ray reflectivity values as a function of the incident angle on each Mirror Shell. More detailed results are in ref. 10, 11 and the latest ones are provided in ref. 12. Various adhoc data processing routines are continuously being developed to meet specific analysis needs.

FIGURE 2 : EUV typical image.



2D Isoplot View 2D View 3D View

Figure 2 is an image of FM2 MM at best-focus location using three standard representations.

FIGURE 3 : X-ray scan plot

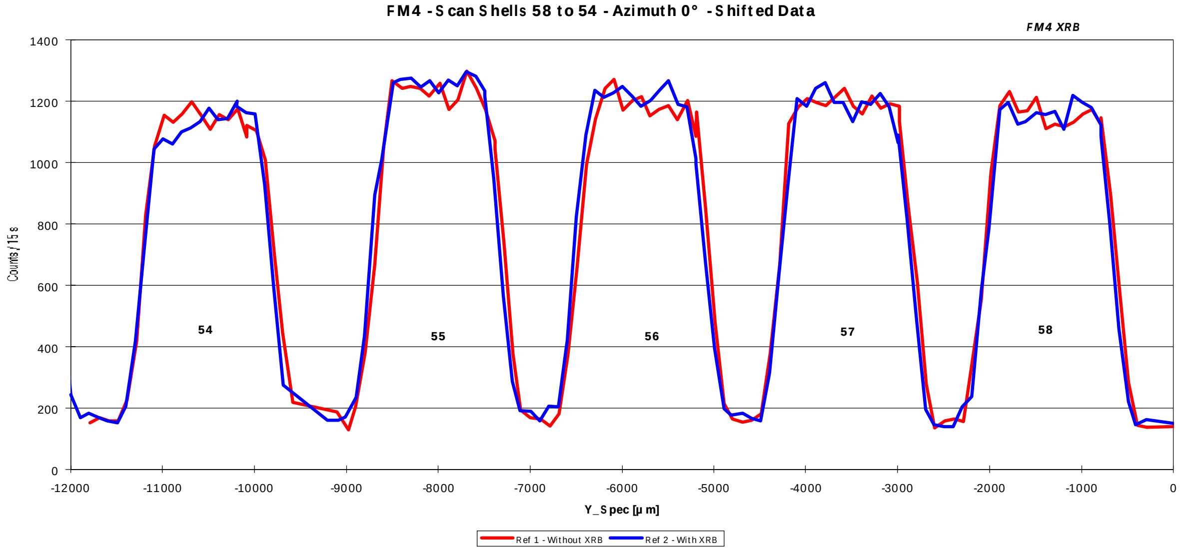


Figure 3 presents the results of a synchronous scan of a Mirror Module and a detector located at the telescope focus in front of the X-ray pencil beam. The result is the recorded fluxes, showing the position of each Mirror Shell.

FIGURE 4 : X-ray reflectivity measurement results

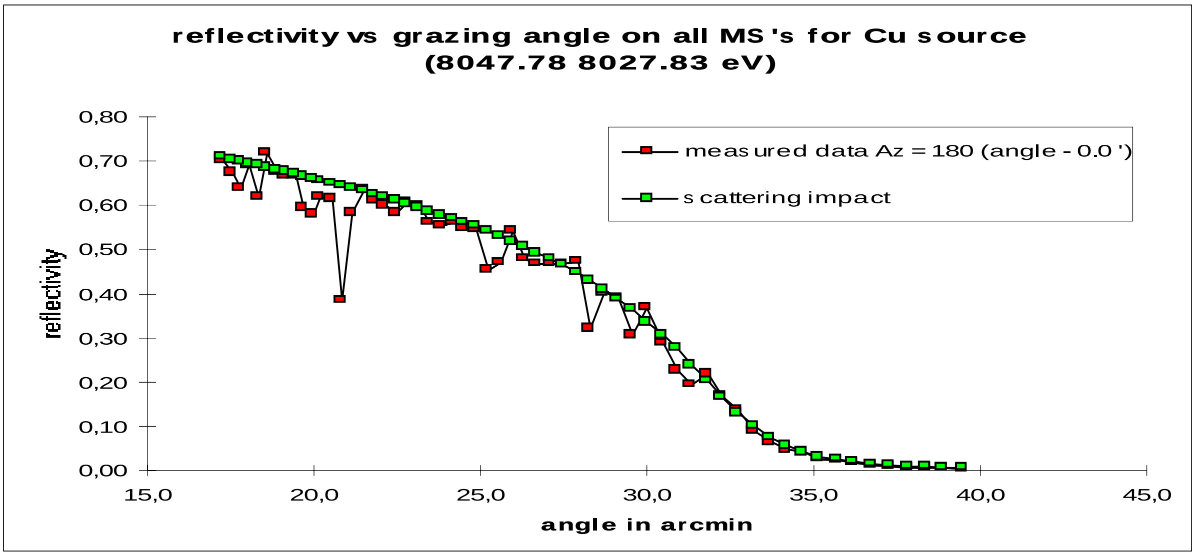


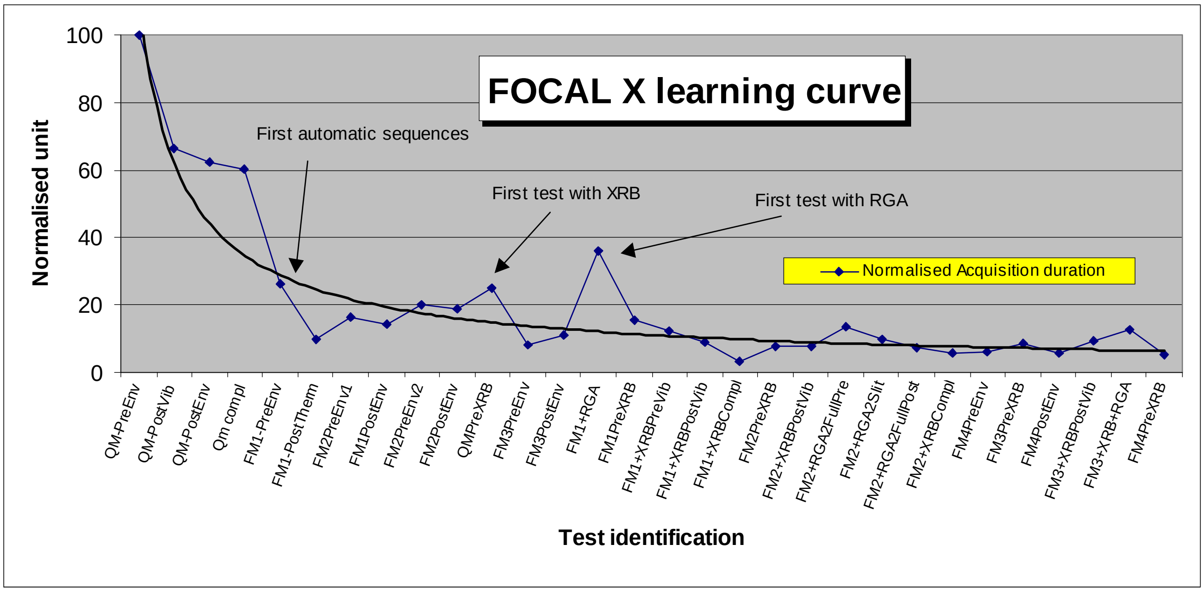
Figure 4 is the reflectivity measurement results obtained on each Mirror Shell, given as a function of the Mirror Shell grazing incidence angle at about 8 keV. It is essentially the ratio between the reflected and incident fluxes.

2.5 FOCAL X learning curve

As schedule was very tight, development activities took place in parallel with test periods. At the beginning, for the first QM testing, most of the activities were in manual mode, forcing test teams to move from one place to the other around the facility to control the equipment. The operation of the facility was continuously made more and more efficient and comfortable : the commands were centralised in the command room on workstations, automatic sequences were developed and validated, equipment and procedures were made more reliable.

The amount of results produced during each test campaign has been evaluated and an average weight was given to each type of measurement. The influence of the weighting factor is very small. The same type of curve is obtained even with a variation of 50% of this factor.

FIGURE 5 : FOCAL X learning curve.



A “Normalised Acquisition Duration” was defined as the ratio between the actual test duration and the number of acquisitions taken and normalised to 100 for the first test. A typical “learning curve” could be seen on fig 5. An improvement factor of about 20 is noticed. It means that, the same measuring sequence taking 20 days at the beginning could be performed now in 1 day. This improvement is not fully visible on the respective test durations because more sophisiticated tests were introduced to take advantage of the increased facility efficiency. Up to now, more than 10 000 images were acquired, 2 000 shells were scanned and 2 000 reflectivity measurements were performed during more than 400 days under vacuum, excluding set-up and development test periods.

3 Specific tests

3.1 XRB Test

The necessity to implement a device to reduce straylight level in the focal plane for sources located outside the telescope FOV was discovered late in the course of the project (see ref. 14). However, its design, manufacturing and testing was realised without shifting the overall telescope schedule. This test, not foreseen at the beginning of the project, was performed using the general capabilities of FOCAL X and is reported in details in ref. 15.

The X-ray Baffle (XRB) objective is to reduce off-axis straylight coming from sources between 30 arcmin and 80 arcmin. These rays are singly reflected on the mirror shell hyperbola surface and are contaminating image at the detector position. The XRB is constructed as a serie of “sieve plates”, mounted in line with the entrance aperture of the mirrors, constituting a kind of “pre-collimator”, blocking about 80 % of the single reflected beam. After XRB integration, it was necessary to check that

1. no degradation of image quality occurs,
2. effective area on axis is not decreased,
3. alignment of XRB with respect to MM is optimum and remains stable after vibrations,
4. reduction factor corresponds to the expected value.

To achieve these goals, the following philosophy was applied :

1. Acquire reference data before XRB integration (image quality, on-axis effective area, straylight amount (up to 1.5°), MSs width and position, vignetting function from –20 arcmin to + 20 arcmin.,
2. XRB is integrated on the MM and then vibrated.
3. The tests performed before XRB integration are repeated and compared.

3.2 RGA Test

The Reflection Grating Assembly (RGA)[16,17] (figure 6) comprises 32 stacks containing up to 8 gratings. For diagnosis purpose, it was necessary to acquire data about the overall RGA quality and also about each individual stack of gratings. To achieve this goal, a test procedure, using only a small part of the EUV collimated beam was set-up. A slit system was designed, manufactured and integrated. A typical RGA test sequence is sketched in figure 7. An alignment procedure of the mask with respect to the EUV beam and with respect to the MM was designed. After reference measurement of the MM+RGA, the RGA alone was submitted to vibration and thermal cycling test and then reassembled with the MM. Optical measurement was repeated. As the overall quality was not degraded, the slit test was not repeated.

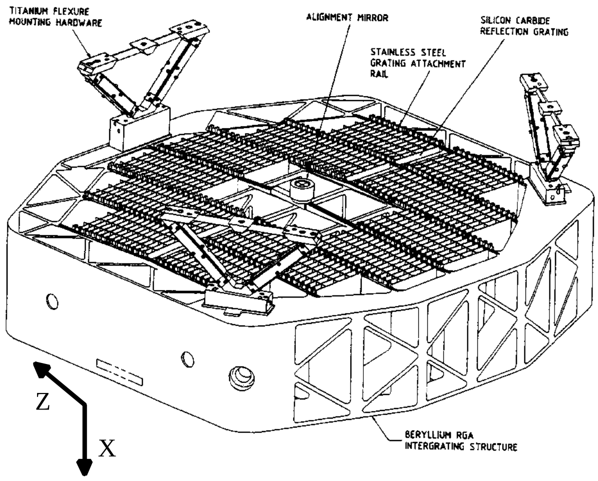


FIGURE 6 : RGA Schematic view

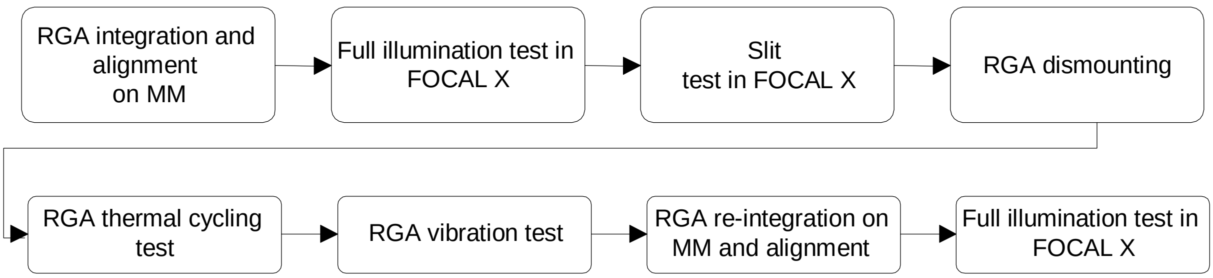


FIGURE 7 : MM + RGA Test sequence

3.3 Alignment lens crosshair lateral position

Each MM is equipped with an alignment lens, materialising the optical axis . The crosshairs are engraved on the lens surface and their centre must coincide with the MM optical axis. It was asked to measure the crosshair centre lateral position with respect to the MM optical axis. A test and data reduction procedure was designed. This measurement has been performed on the four MM FMs.

During the vacuum test sequence, the telescope and detector are positioned at the best focus location. An aluminium filter is used in front of the CCD to reject the visible light. Then an image is acquired for each specimen rotation from -180° to +180° by step of 45°, so 8 images. After the test, the images are summed on one single image and the co-ordinates are found. Then a best circle is computed, passing through the spot centres, giving the decentring between FOCAL X rotation table axis and MM optical axis.

At atmospheric pressure, a theodolite vertically aligned is pointed towards the alignment lens crosshair and then the MM is rotated from -180° to +180° by step of 45° (see figure 8). For each rotation, the MM is translated to keep the crosshair centre at the same location. The displacements are recorded and then analysed to give the decentring between FOCAL X rotation table axis and alignment lens crosshair centre.

Gathering and processing data leads to the determination of the relative lateral position of the alignment lens crosshair with respect to the MM optical axis with an acceptable accuracy : about 0.1 mm.

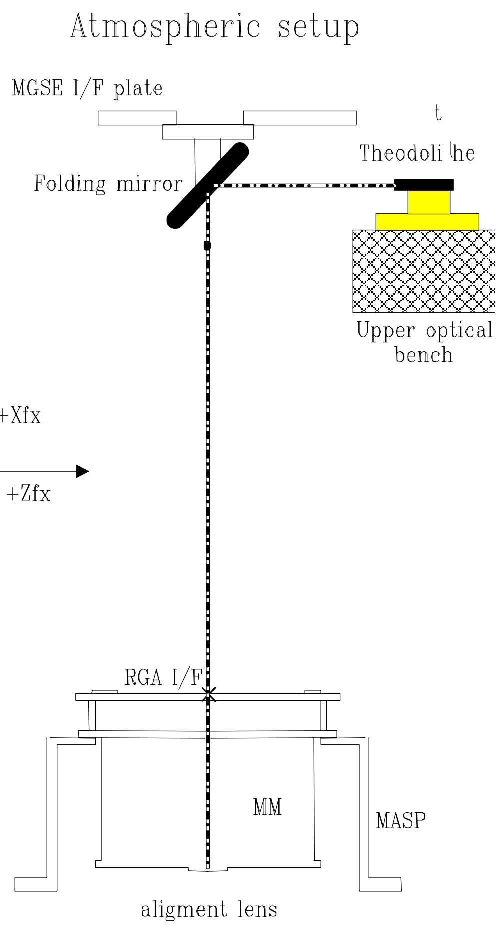


FIGURE 8 : Alignment lens position measuring set-up

4 XMM Test programme at CSL : Summary

Various types of tests were performed at CSL, making extensive use of the facilities :

1. Environmental tests : the goal was to check that MM optical performance is not degraded by thermal cycling or vibrations. A test sequence consists of an optical reference test, a thermal cycling test, a vibration test and a final optical test. In some cases (QM, FM1 and FM2), a third optical test sequence is run.
2. X-ray Baffle test : the goal is to check that the XRB is efficient, correctly integrated and does not degrade MM optical performance on axis. A test sequence consists of an optical reference test, integration of XRB, vibration of MM equipped with XRB and a final optical test. For FM1, an intermediate optical test sequence was performed before vibration test.
3. Reflection Grating Assembly test : the goal is to check the RGA optical quality, the alignment wrt the MM.
4. Complementary tests are deeper measurements performed to get a better knowledge of the MM behaviour.

TABLE 5 : XMM MM tests at CSL

Test article \ Test type	QM MM	STM1,2&3	FM1 MM	FM2 MM	FM3 MM	FM4 MM
Environmental	18/03/96-30/06/96	26/09/96-9/01/97[(2)]	1/02/97-11/04/97	14/03/97-9/06/97	4/8/97-10/10/97	14/04/98-10/6/98
X-Ray Baffle	22/07/97-06/08/97[(1)]	NA	10/11/97-21/12/98	20/01/98-16/02/98	18/05/98-21/06/98	14/08/98-22/09/98[(3)]
Refl.Grat.Ass.	NA	NA	20/10/97-4/11/97	16/02/98 1/03/98	23/06/98-3/7/98	23/09/98-20/10/98[(3)]
Complement.	8/07/96-6/08/96	NA	5/01/98-15/01/98	31/03/98-12/04/98	6/7/98-11/07/98	NA

[(1)] : only reference test before XRB integration was performed.
[(2)] : only vibration test has been performed
[(3)] : as scheduled.

CSL, one of the four ESA co-ordinated facilities, houses vibration, thermal and optical test facilities. Using these test capabilities gathered at the same place allowed an important reduction of the number of transports. The savings may be estimated to about 10 000 ECU per transport, taking into account costs of transportation itself, insurance, nitrogen for flushing and manpower necessary for management, handling, packing, loading, unloading, cleaning activities. Even more importantly, the time saving can be estimated to 4 days per transportation. Up to now, in the frame of the XMM programme, 25 transports have been saved corresponding to 250 000 ECU plus 100 days. The risk reduction due to the decrease of handling activities and the minimisation of potential contamination linked to transportation activities is also of great importance.

5 Cleanliness aspects

5.1 Introduction

Among other constraints, XMM is critical from contamination point of view, particulate as well as molecular. Therefore, efforts have been focused on designing an efficient clean room. Once the cleanroom was built, its maintenance was essential in order to keep a sufficient level of cleanliness ; in addition, the personnel behaviour and the MM handling have been addressed.

The contamination budget attributed to CSL covers the particulate and molecular aspects and is given per test sequence. Specification has been fixed at a value < 25 ppm for particulate contamination at specimen level and $< 0.5\ 10^{-7}$ g/cm² for the molecular contamination per test period.

5.2 Class 100 cleanroom design

The design of the class 100 cleanroom by CSL is based on the lessons learned and on the experience acquired during previous projects. A flexible tent with plastic walls surrounds the vacuum chamber and is divided in 2 main rooms ; the « working area » and the « storage area ». The first design of the « plastic tent » used PVC walls but due to the risky plasticizer (phthalate) contained within the plastic, it has been decided to remove this material and to replace it by polyethylene which unfortunately shows less transparency than PVC , but is free of plasticizer contaminant. The replacement operation is noted in the figure 10, 11 and 12 (notation 1).

The XMM class 100 is composed of (see figure 9):

- A horizontal laminar wall (about 10 meters long) divided into 8 autonomous modules (32 fans with an adjustable speed)
- A storage area (5 meters high) separated from the working area. A double sliding door allows introduction of the specimen from the class 10 000 into this area.
- A working area separated from the storage area with another sliding door. No air mixing is possible between these two areas due to the two horizontal parallel fluxes blown by the laminar walls.

Before the building of the cleanroom itself, a crane (2 tons capacity – 1 axis) has been erected . The tent surrounds the carrier structure in such a way that the engine and commanding system are totally isolated inside a specific tunnel and outside the clean flux. The crane is usable in storage and working area. A net at the opposite side of the laminar walls closes the class 100 tent. Beyond the fact that this net is « filtering » the air coming from the clean room, it also represents a physical barrier preventing accidental access to the class 100 clean area.

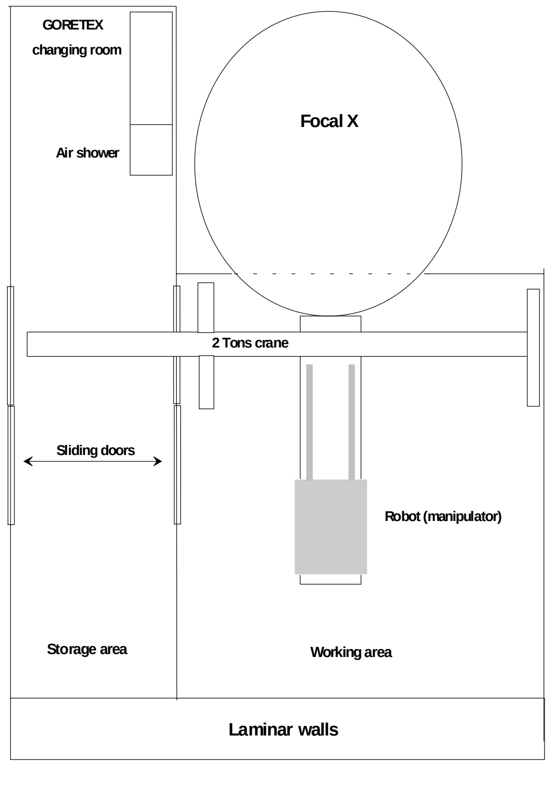


FIGURE 9: Schematic view of the Focal X cleanroom area

In order to comply with the XMM requirements, great care has been taken during the design of the vacuum chamber, mechanisms, OGSE, and equipment. All materials have been chosen, when possible within the materials authorised by ESA (ESA MATLAB 002), by taking into account the dust generation (no chips, flakes or powder) and the potential molecular contamination (low vapour pressure) . When data did not exist in the documentation, outgassing and/or baking tests have been performed. All of these contamination tests have been performed in separate chambers at CSL.

5.3 Cleanliness measurement

Two types of contamination controls are performed at CSL :

- The measurement of the contamination during tests campaign
- The measurement of the contamination during routine periods (monitoring)

During atmospheric sequences of a test campaign, the particulate contamination is measured daily. A number of samples are distributed within the Focal X vacuum chamber as well as in the class 100 area. At the same time, an airborne particle counter is permanently recording the contamination in the air .

During under vacuum sequences of a test campaign, samples (generally 3 for molecular + 3 for particulate contamination) are distributed inside the vacuum chamber. Particulate and molecular samples and analysis methods are compliant respectively to ESA.PSS.01.201 and ESA.PSS.01.705. The location of the samples has been decided early in the program and has always remained the same all along the project duration. Therefore, comparisons between tests are easy and valuable. Among these samples, one is dedicated to record the contamination at the specimen level and is considered as being representative of the contamination viewed by the specimen during the tests at CSL. The other two samples are recording the contamination at facility level. The specimen itself is equipped with 2 molecular samples (gold plated as the mirrors) analysed afterwards by the ESA Environmental Effects Section. A Quartz Crystal Microbalance (QCM) mounted on the MM is also operated.

During routine periods, samples are monitoring the molecular cleanliness of the air inside the class 100. These samples are exposed one month long and are measured on a weekly basis. The particulate contamination of the class 100 and the vacuum chamber is measured by PFO (Particle Fall Out) samples which are distributed within the facility.

5.4 Cleaning aspects - Personnel behaviour

The cleaning of the Focal X vacuum chamber has led to reconsider the cleaning system generally adopted by CSL. The system is linked to the size and the content (OGSE and mechanisms) of the facility. A company specialised in acrobatic cleanings mainly composed of an mountaineering team has been entrusted with the task. As they were not aware of the cleaning procedures in a class 100, CSL has trained them to these specific methods. The normal cleaning of the CSL facilities consists in a cleaning with Isopropylic alcohol and class 100 specific tissues and a final vacuum cleaning under UV light.

Eight full cleanings of the Focal X vacuum chamber have been performed during the overall campaign which represent a cleaning every 3-4 months at the beginning of the project ; the rhythm has been reduced mainly due to the fact that the contamination of the chamber remained very low. In addition to these complete cleanings, regular ones are done just before a vacuum test and are conducted by CSL people. They consist in the cleaning of the optical bench and supported mechanisms and of the detector platform.

CSL people are well trained and experienced to work inside a class 100 ; the adaptation to the Focal X class 100 was easy.

5.5 Contamination results and conclusion

Three graphs represent :

- fig 10 : the evolution of the particulate contamination from the beginning of the XMM project inside the vacuum chamber and in the class 100
- fig 11 : the evolution of the particulate contamination inside the vacuum chamber during the optical tests
- fig 12 : the evolution of the molecular contamination inside the vacuum chamber during the optical tests.

In February 1996, the plastic walls of the class 100 clean room (PVC at the origin) have been exchanged with polyethylene walls as recommended by ESA (noted “1”). The full cleanings of the vacuum chamber by the specialised company are noted “2”.

For the class 100 clean room and the vacuum chamber, the specification used by CSL is the values from the ESA.PSS.01.201 documentation (< 1.5 ppm/24 h for class 100 and < 60 ppm/24 h for class 10 000). In conclusion, it is observed that from the beginning (around April 96), the contamination remained always under the specification as well for the class 10 000 as for the class 100.

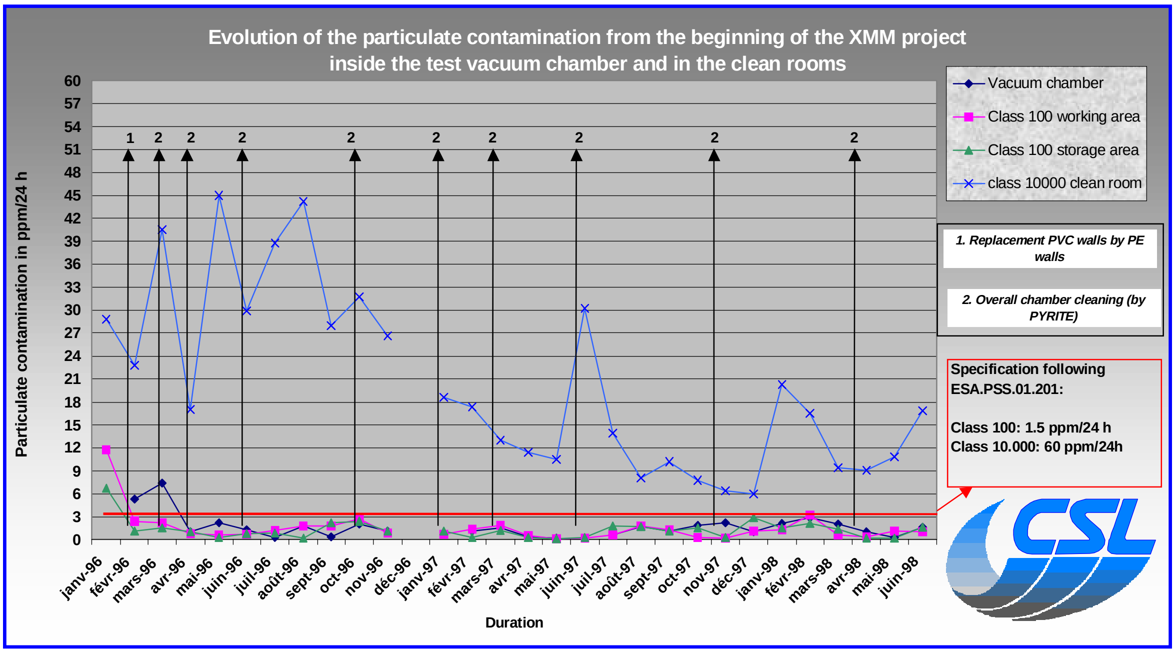


FIGURE 10 : Evolution of the particulate contamination from the beginning of the XMM project.

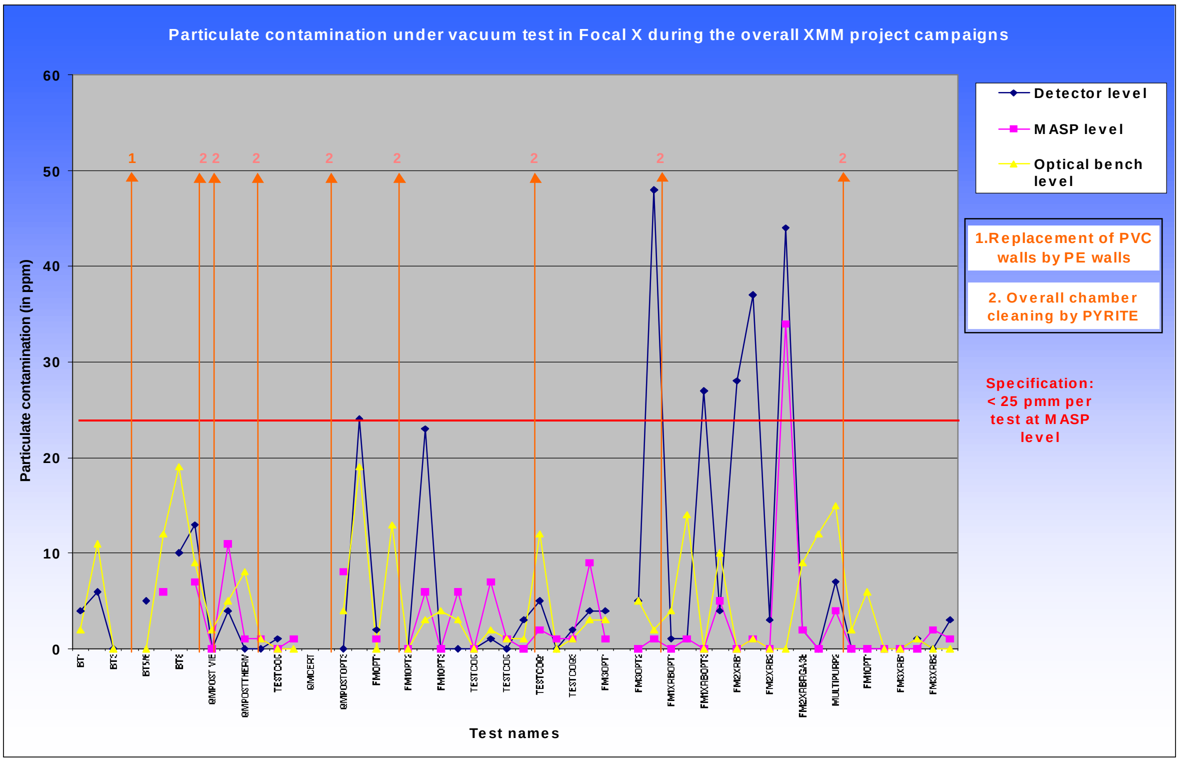


FIGURE 11 : Evolution of the particulate contamination under vacuum testing in Focal X during the overall project campaigns.

For the XMM project, the specification at particulate level has been fixed at < 25 ppm per vacuum test at specimen level. It can be noticed that the specification has been met except in a few well -identified cases, mainly at the detector level. At specimen level (MASP), the specification has never been violated.

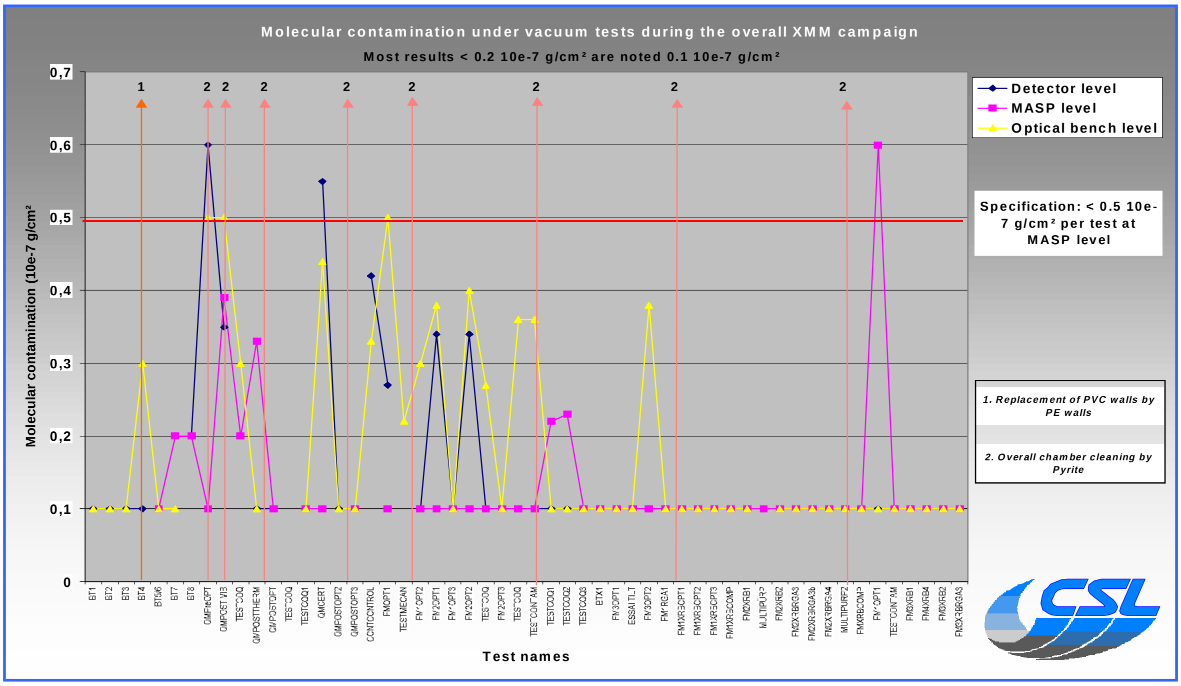


FIGURE 12 : Evolution of the molecular contamination under vacuum test during the overall test campaign.

The detection limit for molecular contamination detection is commonly fixed at 0.2 10^{-7} g/cm². Values below this limit are not representatives. In order to facilitate the reading of the figure, the following convention has been decided : all values < 0.2 10^{-7} g/cm² shall be noted 0.1 10^{-7} g/cm².

In conclusion, it has been demonstrated that a realistic contamination budget associated to an adapted design for a vacuum chamber, an adapted cleaning method and a good personnel behaviour may lead to a high cleanliness state in a rather short time.

6 Conclusion

The capabilities of FOCAL X, the dedicated XMM EUV and X-ray test facility, have been recalled. Its flexible design has been underlined. An overview of the various activities linked to the building of this facility and of all the tests performed is given. An efficiency increased by a factor 20 over the 18 months test period is reported. The criticality of the cleanliness aspects and the achievements in this field are also presented.

CSL test team developed a good understanding and a expert control of all the technical and scientific aspects. This was the key parameter to be able to take maximum benefit from this facility. This expertise and high level equipment are available and represent an asset for future scientific space programmes. Next generation optical satellite could probably make a valuable utilisation of this powerful and efficient test facility.

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8 References

1. D. Lumb, H. Eggel, R Lainé, A Peacock, "X-ray Multi-Mirror Mission - an overview", SPIE Denver 1996, Conference 2808-32
2. J. van Casteren, "The X-ray Multi-Mirror spacecraft, a large telescope", SPIE Denver 1996 conference 2808-33

3. Ph. Gondoin, D. de Chambure, K. van Katwijk, Ph. Kletzkine, D Stramaccioini, B. Aschenbach, O. Citterio, R. Willingale, "The XMM Telescope", SPIE Vol 2279, pp86-100, 1994
4. D. de Chambure, R. Lainé, K.van Katwijk, J van Casteren, P. Glaude, "The Status of the X-ray Mirror Production for the ESA XMM Spacecraft", SPIE Denver 1996, Conference 2808-35
5. Ph. Gondoin, B. Aschenbach, H. Brauninger, D. de Chambure, J.P. Collette, R. Eggert, K. van Katwijk, D; Lumb, A; Peacock, Y. Stockman, J. Ph. Tock, R; Willingale, "X-ray Performance of a Qualification Model of an XMM Mirror Module", SPIE Denver 1996
6. Y. Stockman, J.Ph. Tock, E. Mazy, D. de Chambure, Ph. Gondoin "X-ray and EUV characterisation of the first XMM Flight Mirror Module", 3rd International Symposium on Environmental Testing for Space Programmes at ESTEC, Noordwijk, June 1997
7. Y. Stockman, J.P. Collette, J. Ph. Tock, D. de Chambure, Ph. Gondoin, "Optical testing of XMM Flight Module I and II at the vertial EUV/X facility", SPIE San Diego 1997
8. Y. Stockman, P. Barzin, H. Hansen, J. Ph. Tock, D. de Chambure, Ph. Gondoin, "Simulation of EUV XMM MM star field from actual measurements", first XMM Workshop, ESTEC Noordwijk, these proceedings.
9. J.P. Collette, Y. Stockman, J.Ph. Tock, Ph Kletzkine, R. Lainé, A. Vignelles "Performance of XMM Optics vertical test facility", SPIE Denver 1996
10. J. Ph. Tock, JP Collette, A Cucchiaro, I Domken, Y. Stockman, Ph Kletzkine, A. Vignelles, "FOCAL X : a test facility for X-ray telescopes", 3rd International Symposium on Environmental Testing for Space Programmes, Noordwijk 1997.
11. Y. Stockman, J.P. Collette, J. Ph. Tock, D. de Chambure, Ph. Gondoin, "Optical testing of XMM Flight Module I and II at the vertical EUV/X facility", SPIE San Diego 1997
12. A. Cucchiaro, I. Domken, P. Jamotton, I. Tychon and JP. Tock "New facility for extreme ultraviolet and X-ray testing", 19 th Space Simulation Conference NASA CP3341 Baltimore Octobre 1996
13. J. Ph. Tock, J.P. Collette, Y. Stockman, "Calibration and Upgrades of the XMM vertical EUV/X Test Facility : Focal X", SPIE Sand Diego, August 97.
14. D. de Chambure, K van Katwijk, R Lainé, J. van Cateren, G. Peterson, M. Côté, B Aschenbach, R. Willingale, D. Schink, A. Frey, W. Rühe, Y. Guttierez, F. Draheim " Reducing the optical and X-ray stray light in the ESA XMM telescopes", International Conference on Space Optics 1997 - Toulouse
15. Y. Stockman, I. Domken, H. Hansen, J.Ph. Tock, T.A. Decker, A. Rasmussen, A.J.F. den Boggende, J.W. den Herder, F. Paerels, G. Bagnasco, D. de Chambure, C. Erd, Ph. Gondoin, "XMM Flight Mirror Modulewith Reflection Grating Assembly and X-ray Baffle Testing", SPIE San Diego 1998
16. S.M. Kahn, J. Cottam, T.A. Decker, F.B.S. Paerels, S.M. Pratuch, A. Rasmussen, J. Spodek, J.V. Bixler, A.C. Brinkman, J.W. den Herder, C. Erd, "the reflection grating arrays for the reflection grating spectrometer on-board of XMM", SPIE Vol 2808, pp450-462, Denver 1996
17. A.C. Brinkman, H.J.M. Aarts, A.J.F. den Boggende, T. Bootsma, L. Dubbeldam, J.W. den Herder, J.S. Kaastra, P.A.J. de Korte, B.J. van Leeuwen, R. Newe, E. van Zwet, S.M. Kahn, C.J. Hailey, T.A. Decker, F.B.S. Paerels, S.M. Pratuch, A. Rasmussen, G. Branduardi-Raymont, P. Guttridge, J.V. Bixler, K. Thomsen, A. Zehnder, C. Erd, "The Reflection Grating Spectrometer on-board of XMM", SPIE Vol 2808, pp463-480, Denver 1996.