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New Generation Polar-orbiting Meteorological Satellite of China and its Greenhouse gases Monitoring Payload

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I. INTRODUCTION

Meteorological satellites have become an irreplaceable weather and ocean observing tool. Since the first Chinese polar-orbiting meteorological satellite was launched successfully in 1988, there are totally 13 meteorological satellites that were launched into both sun synchronous and geostationary orbit. China is among the few countries in the world which are simultaneously operating both orbiting meteorological satellites. All the satellites have been incorporated into the global constellations of operational meteorological satellites within the WMO framework. More satellites are under construction to be the second generation ones.

II. CHINESE METEOROLOGICAL SATELLITE

Chinese meteorological satellite, named Fengyun (FY, wind-cloud) Satellite, has a polar-orbiting series and a geostationary series. The name of a specific satellite is combined with a number in the front and a letter in the back. The odd number stands for polar-orbit, and the even number stands for geostationary orbit. The letter in the back of the name stands for the order of the satellite in its series. Up to now, 7 polar-orbiting (FY-1A/B/C/D and FY-3A/B/C) and 6 geostationary (FY-2A/B/C/D/E/F) satellites were launched. FY data has been being intensively applied not only to meteorological monitoring and prediction but also to many other fields regarding ecology, environment, disaster, space weather and so and. The FY data sharing system, FengyunCast, is now one of the three components of global meteorological satellite information dissemination system, GEONETCast. The first satellite of the new generation polar-orbiting series, FY-3A, was launched on 27 May, 2008, demonstrating the FY polar-orbiting satellite and its application completed a great leap to realize three-dimensional observations and quantitative application.

Tab. 1. Fengyun (FY) Satellite series

Name	Orbit	Launching time	Function & State
FY-1A	polar-orbit	1988.09.07	research, retired
FY-1B	polar-orbit	1990.09.03	research, retired
FY-1C	polar-orbit	1999.05.10	business, retired
FY-1D	polar-orbit	2002.05.15	business, retired
FY-2A	geostationary orbit	1997.06.10	research, retired
FY-2B	geostationary orbit	2000.06.25	research, retired
FY-2C	geostationary orbit	2004.10.18	business, retired
FY-2D	geostationary orbit	2006.12.08	business, active
FY-2E	geostationary orbit	2008.12.23	business, active
FY-2F	geostationary orbit	2012.01.13	business, active
FY-3A	polar-orbit	2008.05.27	research, active
FY-3B	polar-orbit	2010.11.05	research, active
FY-3C	polar-orbit	2013.09.23	business, active

The latest Chinese meteorological satellite, FY-3C, was launched in 2013. Much improvement was implanted on the function and performance of the payloads, for instance, the additional occultation detector, the function of lunar calibration, etc.

Fig. 1. Meteorological Satellite FY-3C

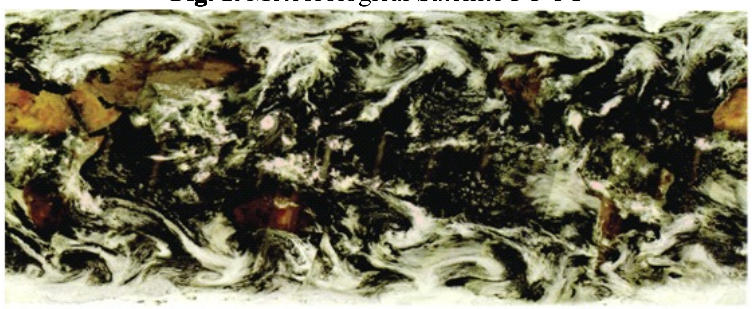


Fig. 2. Global nephogram of Visible-Infrared Scanning Radiometer (VISR) on FY-3C

With the development of the satellite technology, the FY Series focus on the global issues increasingly and a good many new-style payloads are on the schedule, here the Hyper-spectral Green-house Gases Monitor (HGGM) is one of them.

III. DEVELOPMENT OF HYPER-SPECTRAL GREEN-HOUSE GASES MONITOR (HGGM)

HGGM is a high-resolution Fourier transform spectrometer, built with the capability to detect the absorption spectra data of O_2 (near infrared) and CO_2, CH4, CO (short wave infrared), thus offering data on global distribution of greenhouse gases, climate change, etc. It is a new payload belonging to satellite FY-3(04), namely FY-3D once on orbit.

Greenhouse gases on-orbit observation is an important field in the atmosphere remote sensing currently. Both the USA and Japan have made a step forward by sending the specialized monitoring payloads onto space individually. Drawing lessons from the pioneers, and also based on the Chinese applications and FY-3 satellite platform features, the main Indicators of HGGM are given as following table.

Tab. 2. Main indicators of HGGM

Indicators Item		Indicators			
		Band 1	Band 2	Band 3	Band 4
Band (μm)		0.75-0.77	1.56-1.72	1.92-2.08	2.20-2.38
Spectral Resolution (cm^{-1})		≯0.6	≯0.27	≯0.27	≯0.27
SNR	Range	＞320	260~300	160~300	140~300
	Conditions	@ albedo 0.3, solar zenith angle 60°	@ albedo 0.2, solar zenith angle 60°	@ albedo 0.2, solar zenith angle 60°	@ albedo 0.1, solar zenith angle 60°
Target		CO_2	CO_2、CH_4	CO_2	CO、CH_4
Scanning View		±35° (cross orbit) @836km altitude			

According to the Indicators above, the overall plan of HGGM is given as below,

a) The target signal is introduced with a pointing mirror mechanism;
b) The interference modulation of the input target beam is done with a specific interferometer;
c) The interference beam is compressed to an appropriate aperture by a reflecting compression optic-system, and then spitted into 4 bands by a transmission-type beam-splitter;
d) Detectors invert interference beam signal into interference figure signal for each band;
e) Signal amplification and filtration of the interference figure is done by analogy signal processing transponder, and then is digitized by ADC;
f) The digitized signal is then sent to satellite communication system, finally sent to the ground processor.

The operating principle is shown below.

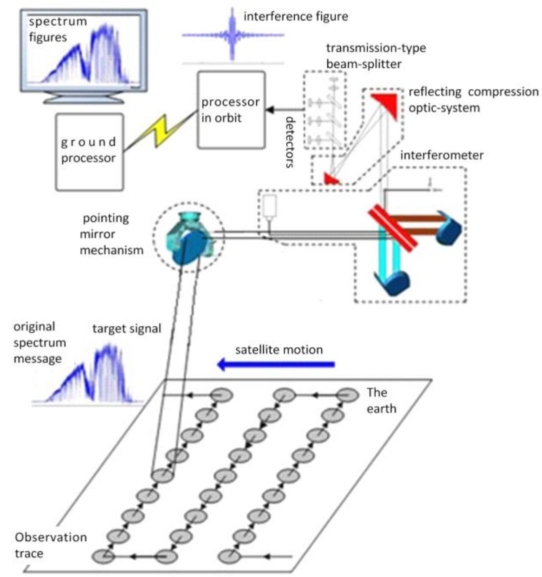
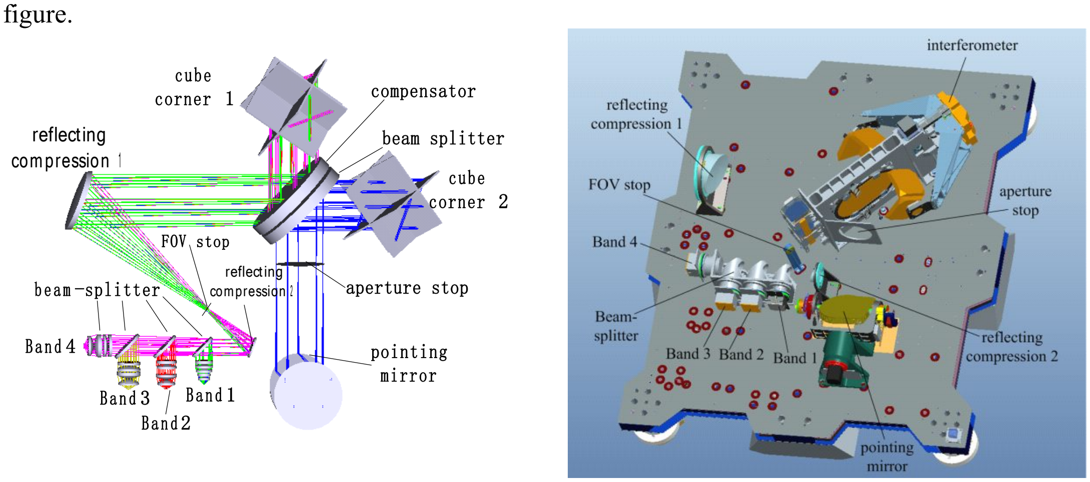


Fig. 3. Schematic diagram of HGGM

HGGM is approximately 150kg in mass, and 1m×1m×0.8m in volume. The main structure is seen in next figure.



(a) Optical System (b) Main Structure

Fig. 4. Structure of HGGM

The optical spectrum interferometer, core part of the monitor, in twin cube corners and swinging arm structure, could realize the variation modulation of the incidence beam. The swinging motion of the arm induces the OPD (optical path difference) of the two specialty beams divided from the incidence beam changing with time, thus the corresponding interference field obtained at the output end. Hence, the optical system stableness and the OPD speed stability of the interferometer would influence the spectrum resolution, SNR and other key indicators efficiently.

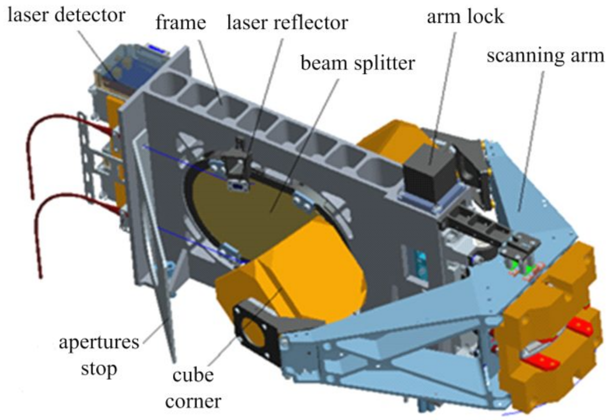


Fig. 5. Optic-Structure of the interferometer

A pointing mirror is laid at the entrance of the monitor, observing the terrestrial atmosphere. The pointing mechanism can rotate in two-dimensions, one is scanning across the orbit, another is compensating along the orbit, to defend the stabilization of the monitor on object observation. Also, the staring function of the pointing mechanism helps the monitor to realize the observation of solar blaze, the blaze reflected by the ocean surface.

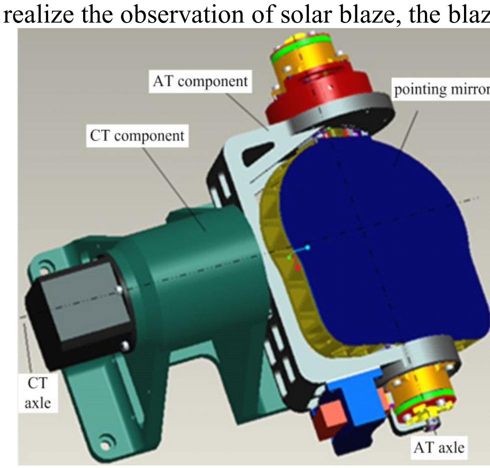


Fig. 6. Optic-Structure of the pointing mirror mechanism

Moreover, calibrating system both on radiation realm and spectrum realm on orbit is built, to ensure the quantitative analysis and high precision in application. The on-orbit calibration unit is developed by TNO.

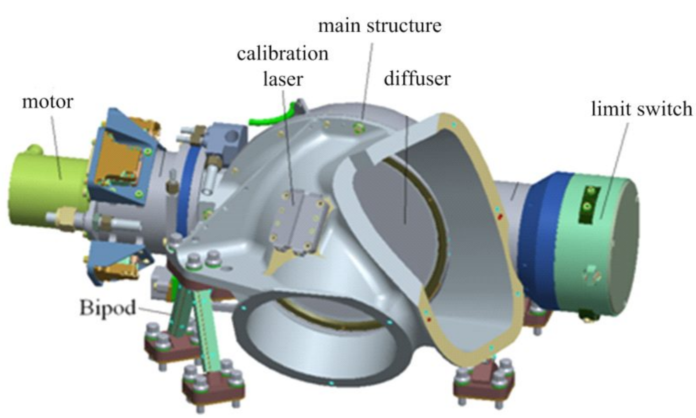


Fig. 7. Optic-Structure of the calibration unit

The indicators of the HGGM design can be seen in the table below.

Tab. 3. Indicators of the HGGM design

Indicators Item	Indicators			
	Band 1	Band 2	Band 3	Band 4

Band (μm)		0.75-0.77	1.56-1.72	1.92-2.08	2.20-2.38
Spectral Resolution (cm^{-1})		0.58	0.26	0.26	0.26
SNR	Range	325	277	168	141
	Conditions	@ albedo 0.3, solar zenith angle 60°	@ albedo 0.2, solar zenith angle 60°	@ albedo 0.2, solar zenith angle 60°	@ albedo 0.1, solar zenith angle 60°
Scanning View		±35° (cross orbit)@836km altitude			

IV. CRITICAL TECHNOLOGIES

Obviously, HGGM is an integration of space geometrical optics, physical optics and optical spectroscopy. It is a complex system with many high- precision control links and high- integration requirements. Although lack of experience on the greenhouse gases monitoring, a new realm in China, we have conquered many critical technologies to achieve intention during the research, for instants, space-borne large-aperture high-efficiency Fourier interferometer, high-precision long-life pointing mechanism, on-orbit micro-vibration isolation, etc.

A. Space-borne large-aperture high-efficiency Fourier interferometer

As the core part of the monitor, the interferometer would influence the key indicators efficiently. Generally, max. OPD, percentage modulation and speed stability of swing arm are regarded as key indicators of the interferometer. The performance of the interferometer is as below.

Tab. 4. Test results on the performance of the interferometer

Indicators Item	Indicators	Test Results
Max. OPD	≮±2.5cm	±2.52cm
Percentage Modulation	Band 1：≮53.5% Band 2：≮84% Band 3：≮87% Band 4：≮88.5%	Band 1：≮54.1% Band 2：≮84.7% Band 3：≮87.4% Band 4：≮89.2%
Speed Stability of Swing Arm	≮99%	99.72%

The compliance of the test indicates this conundrum has been conquered.

B. High-precision long-life pointing mechanism

The pointing mirror can scan across the orbit around CT axle, and compensate along the orbit around AT axle. The requirement of pointing precision on AT axle is 0.02°; the switch on CT axle is required to be 14°/0.35s, and the pointing precision requirement on CT axle is 0.04°; Furthermore, cycle index on orbit is as many as more than 2 million times.

The test of performance indicates that all the indicators on precision above are satisfied, and the cycle index is proven with the length of life test on the ground.

C. On-orbit micro-vibration isolation

The Fourier interferometer is sensitive to the vibration around. In order to keep interferometer a quiet environment on orbit, a vibration isolation system is developed. This isolation system is located between HGGM optics-structure and the platform board, as is shown in the figure below. It is locked during the launch phase, and released after on the orbit.

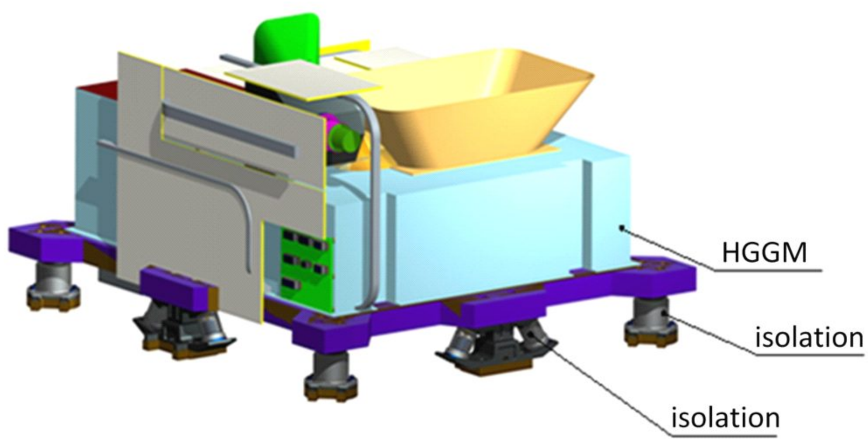


Fig. 8. Layout of the vibration isolation system

Thanks to the performance of the isolation system, HGGM worked well during the satellite micro-vibration test. Furthermore, the isolation system acted well during QM vibration test in locking statement, and also released successfully after the vibration test.

V. TEST AND VERIFICATION OF HGGM

After the assembly of the payload, a series tests and experiments are conducted to verify the design. The test of the spectral resolution and SNR, key indicators of HGGM, are shown below.

Tab. 5. Spectral resolution test results

Spectral Resolution	Indicator (cm^-1)	Test (cm^-1)
Band 1	≯0.6	0.5843
Band 2	≯0.27	0.2695
Band 3	≯0.27	0.2425
Band 4	≯0.27	0.2397

Tab. 6. SNR test results

SNR	Band 1	Band 2	Band 3	Band 4
Indicator	≯320	260~300	160~300	140~300
Test	>325	>295	>174	>140
Remark	@ albedo 0.3, solar zenith angle 60°	@ albedo 0.2, solar zenith angle 60°	@ albedo 0.2, solar zenith angle 60°	@ albedo 0.1, solar zenith angle 60°

Ground calibration test, including radiometric calibration and spectrum calibration, is to verify the radiometric and spectrum quality of the monitor. With the calibration test, the absolute calibration coefficients, relative calibration coefficients and spectrum stability of the monitor could be obtained. A high steady and precise lamp-house and a brief test chain are required to conduct the test. Fig.9 gives the test setup.

Fig. 9. Ground calibration test setup

Moreover, a series of reliability tests are proceed, as is shown below.

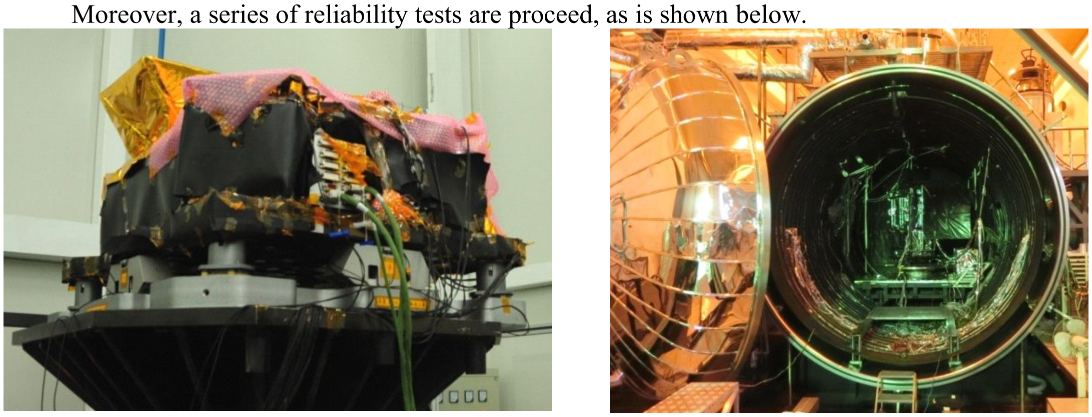


Fig. 10. Ground reliability tests

VI. CONCLUSION

During the last 30 years, China has constructed the meteorological aerospace with business and in series, depending on the 13 meteorological satellites launched, leading significant contributions to many countries.

Hyper-spectral Green-house Gases Monitor (HGGM) is an additional payload aiming at global climate change observing, and would be sent to orbit by FY-3(04), namely FY-3D once launched. Four bands are set during 0.7um to 2.4um in spectrum, and the min. spectral resolution attains to 0.27cm-1, also the max. SNR attains to 325 at albedo 0.3, solar zenith angle 60°. By now, the critical technologies have been resolved and the production has been developed and validated. The application of HGGM would bring active influence on the monitoring global green-house gases, research on relation between the letting of green-house gas and the global climate change, etc.

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