Analytical & Experimental Study on Microvibration Effects of Satellite

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ABSTRACT

Number of components and payload systems installed in satellites were found to be exposed to various disturbance sources such as the reaction wheel assembly, the control moment gyro, coolers, and others. A micro-level of vibration can introduce jitter problems into an optical payload system and cause significant degradation of the image quality. Moreover, the prediction of on-orbit vibration effects on the performance of optical payloads during the development process is always important. However, analyzing interactions between subsystems and predicting the vibration level of the payloads is extremely difficult. Therefore, this paper describes the analytical and experimental approach to microvibration effects on satellite optical payload performance with integrated jitter analysis framework, microvibration emulator and satellite structure testbed.

1. 가
가
/
(1~3)
,
,
(pointing stability) 가
,
가
(reaction wheel assembly; RWA) cooler 가

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$$, \quad (4)$$

(5)

(testbed)⁽⁶⁾

2.

2.1

citation)

(1)

$$m(t) = C\Omega^2 \sin(2\pi h\Omega t + \alpha) \quad (1)$$

Fig. 1 Analytical model of RWA with imbalance⁽¹⁾

C (coefficient)	h (harmonic number)	γ (harmonic number)
0.000000	1	0.000000
0.000000	2	0.000000
0.000000	3	0.000000
0.000000	4	0.000000
0.000000	5	0.000000
0.000000	6	0.000000
0.000000	7	0.000000
0.000000	8	0.000000
0.000000	9	0.000000
0.000000	10	0.000000
0.000000	11	0.000000
0.000000	12	0.000000
0.000000	13	0.000000
0.000000	14	0.000000
0.000000	15	0.000000
0.000000	16	0.000000
0.000000	17	0.000000
0.000000	18	0.000000
0.000000	19	0.000000
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0.000000	28	0.000000
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0.000000	84	0.000000
0.000000	85	0.000000
0.000000	86	0.000000
0.000000	87	0.000000
0.000000	88	0.000000
0.000000	89	0.000000
0.000000	90	0.000000
0.000000	91	0.000000
0.000000	92	0.000000
0.000000	93	0.000000
0.000000	94	0.00

(1) RWA

가

가

(1)

가

(2)~(3)

$$\begin{aligned} & \begin{bmatrix} M_t & 0 \\ 0 & M_t \end{bmatrix} \begin{Bmatrix} \ddot{x} \\ \ddot{y} \end{Bmatrix} + \begin{bmatrix} c & 0 \\ 0 & c \end{bmatrix} \begin{Bmatrix} \dot{x} \\ \dot{y} \end{Bmatrix} + \begin{bmatrix} k & 0 \\ 0 & k \end{bmatrix} \begin{Bmatrix} x \\ y \end{Bmatrix} \\ &= \sum_{i=1}^n C_{rad_i} \Omega^2 \begin{Bmatrix} -\sin(h_{rad_i} \Omega t) \\ \cos(h_{rad_i} \Omega t) \end{Bmatrix} \end{aligned} \quad (2)$$

$$\begin{aligned}
& \left[\begin{array}{cc} I_{rr} & \frac{1}{2} \tilde{I} \sin(2\Omega t) \\ \frac{1}{2} \tilde{I} \sin(2\Omega t) & I_{rr} \end{array} \right] \left\{ \begin{array}{c} \ddot{\theta} \\ \ddot{\phi} \end{array} \right\} \\
& + \Omega \left[\begin{array}{cc} \frac{c_\theta}{\Omega} - \tilde{I} \sin(2\Omega t) & I_{zz} \\ -I_{zz} & \frac{c_\theta}{\Omega} + \tilde{I} \sin(2\Omega t) \end{array} \right] \left\{ \begin{array}{c} \dot{\theta} \\ \dot{\phi} \end{array} \right\} \\
& + \left[\begin{array}{cc} k_\theta & 0 \\ 0 & k_\phi \end{array} \right] \left\{ \begin{array}{c} \theta \\ \phi \end{array} \right\} = \sum_{i=1}^n C_{i\omega_i} \Omega^2 \left\{ \begin{array}{c} \cos(h_{i\omega_i} \Omega t) \\ \sin(h_{i\omega_i} \Omega t) \end{array} \right\}
\end{aligned} \tag{3}$$

$$m_t = M + m_s + 2m_d \quad (4a)$$

$$\tilde{I} = 2m_d r_d^2 + m_s r_s^2 \quad (4b)$$

$$k_\theta = kd_k^2, C_\theta = cd_c^2 \quad (4c)$$

$$\begin{array}{ll} \text{가} & (M_t \gg m_s, m_d, I_{rr}, I_{zz} \gg \tilde{I}), \\ c, k, c_\theta, & k_\theta \quad \text{(damping),} \\ \text{(stiffness),} & \text{(torsional damping)} \\ & \text{(torsional stiffness)} \end{array}$$

. RWA

가

RWA

(5)

(transmitted

force)

$$\begin{Bmatrix} F_x \\ F_y \\ C_x \\ C_y \end{Bmatrix} = \begin{Bmatrix} kx \\ ky \\ k_\theta \theta \\ k_\phi \phi \end{Bmatrix} + \begin{Bmatrix} c\dot{x} \\ c\dot{y} \\ c_\theta \dot{\theta} \\ c_\phi \dot{\phi} \end{Bmatrix} \tag{5}$$

Fig. 2 (5)
waterfall plot

2.2
가
(finite element method; FEM)

가 가
가
가

Fig. 2 Waterfall plot of reaction wheel force disturbances

Fig. 3 Procedure for structural analysis using ANSYS and MATLAB

Table 1 Information of the structure model		
	Satellite main body	Satellite optical body
Spec.	Box type 710×710×710 mm ³ Thickness: 5 mm	Diameter: 300 mm Length: 400 mm Thickness: 1.2 mm
Material property	AL 6061 Young's modulus: 71 GPa Poisson's ratio: 0.35	Stainless steel Young's modulus: 180 GPa Poisson's ratio: 0.22

Fig. 4 Configuration of the satellite structure model

Fig. 5 First six modes of structure model

Fig. 6 Single axis microvibration emulator

Fig. 7 Procedure of emulator input voltage profile

FM

1

Table 2

(5)

Fig.

6

(base structure)

1

3

가

(F)

(V)

(inverse FFT)
가

Table 2 Specification of the microvibration emulator

Specification	1-axis emulator	3-axis emulator
Total mass(kg)	3.5	15
Size(m×m×m)	0.12×0.12×0.15	0.21×0.21×0.21
Force range(N)	0~15	0~15
Frequency range(Hz)	0~400	0~400
Force direction	Z direction	X,Y,Z direction

Fig. 8
rpm) 100
1~100 Hz(60~6000
가(sweep)
Fig. 8
가

3.2

testbed

가

가

Fig. 8 Waterfall plot comparison: RWA, emulator

Fig. 9 Satellite structure testbed

Fig. 10 Analytical & experimental modal test of satellite optical body

(a) 1st mode: 110.5 Hz (b) 2nd mode: 193.9 Hz
(c) 3rd mode: 195.3 Hz (d) 4th mode: 272.8 Hz

Fig. 11 First four modes of satellite optical body

Table 3 Modal test results of satellite optical body		
Mode	ANSYS analytical results[Hz]	Testbed experimental results[Hz]
1	110.5	132.3
2	193.87	191.1
3	195.34	200.3
4	272.76	253.3
5	284.12	261.4
6	343.08	389.3
7	346.11	399.3

Fig. 12 Analytical & experimental modal test of satellite main body

(a) 1st mode: 94.2 Hz (b) 2nd mode: 99.7 Hz
(c) 3rd mode: 115 Hz (d) 4th mode : 175.2 Hz

Fig. 13 First four modes of satellite main body

Table 4 Modal test results of satellite main body		
Mode	ANSYS analytical results[Hz]	Testbed experimental results[Hz]
1	94.24	102.6
2	99.668	104.1
3	115.03	113.1
4	175.26	167.9
5	202.94	192.3
6	209.43	210.1
7	218.98	221.3

free-free

3 2~3 Hz

Fig. 9

3 가

(testbed)

6 가 Fig. 10 Fig. 12
impact hammer

Table 3 Table 4

2.2

Fig.

10 Fig. 12

13 FEM

Fig. 11 Fig.

4. 가

4.1 가

가 가

가

가

testbed

가

가

Fig. 14

가

Table 5 가

Fig. 14 가 2400 rpm

40 Hz, 120 Hz

40 Hz

가 10.8 %, 120 Hz

31.6 %

(a) Analytical approach

(b) Experimental approach

Fig. 14 Comparison of optical payload acceleration with constant wheel speed(2400 rpm)

Table 5 Comparison of optical payload acceleration level

Freq. [Hz]	Analytical (m/s ²)	Experimental (m/s ²)	Error (%)
40	0.0148	0.0132	10.8
120	0.0038	0.0026	31.6

Fig. 15 1~100 Hz(~6000 rpm) 100

가(sweep) (Fig. 2)

Fig. 2

12 N peak

0.1 N peak

가

Fig. 15 Comparison of force disturbance of optical payload with wheel speed sweep(1~100 Hz)

5.

가

가

,

(testbed)

가

가

가

10 %

가

가

(NSL, National Space

Lab)

2009-0091934)

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