KMAG: THE MAGNETOMETER OF THE KOREA PATHFINDER LUNAR ORBITER (KPLO) MISSION

Abs. [#2276]
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Introduction

Korea Pathfinder Lunar Orbiter (KPLO) is the first lunar exploration mission in Korea. Its development started in 2016 and is scheduled for launch in 2020. The mission objectives are demonstration of lunar exploration technologies, construction of a ground station for deep space communication, and scientific investigation of the lunar environment. KPLO is equipped with five science payloads: Lunar Terrain Imager (LUTI), Disruption Tolerant Networking Payload (DTNPL), Wide-Angle Polarimetric Camera (Polcam), KPLO Gamma Ray Spectrometer (KGRS), ShadowCam, and KPLO MAGnetometer (KMAG). The main objective of the KMAG instrument is to provide measurement data of the magnetic field of the Moon using three fluxgate sensors. KMAG will operate on a 100 % duty cycle in nominal phase and extended phase. Measurements will continue and data will be transferred to the Earth until KPLO impacts on the surface of the Moon. KMAG Flight Model (FM) will be delivered to the Korea Aerospace Research Institute (KARI) by 1Q, 2019. After FM delivery, we will perform long-term testing using QM and EQM KMAG to develop the calibration process and pre-processing software.

KPLO

- KPLO (Korea Pathfinder Lunar Orbiter) is a first lunar orbiter in Korea and it is started to develop from 2016 (Launch date 2020, TBD).
- Mass of KPLO is 580.67 kg contained fuel and its size is 1.75 m(W) × 1.71 m(L) × 2.34 m (H).
- Mission life is 1 year at 100 km altitude lunar orbit. After extended mission phase, KPLO's mission will be closed as impact on the surface.
- Payloads
  - **LUTI** (**Lu**nar **T**errain **I**mager) (by KARI)
  - **DTNPL** (**D**isruption **T**olerant **N**etwork experiment payload) (by ETRI)
  - **PolCam** (Wide-Field **Pol**arimetric **Cam**era) (by KASI)
  - **KMAG** (**K**PLO **Mag**netometer) (by KHU)
  - **KGRS** (**K**PLO **G**amma **R**ay **S**pectrometer) (by KIGAM)
  - **ShadowCam** (by NASA)
- KPLO mission objectives
  - Lunar exploration technology demonstration , validation of new space technology
  - Construction of a ground station for deep space communication
  - Scientific investigation on lunar environment
  - Production of topographic map for support to select future lunar landing sites

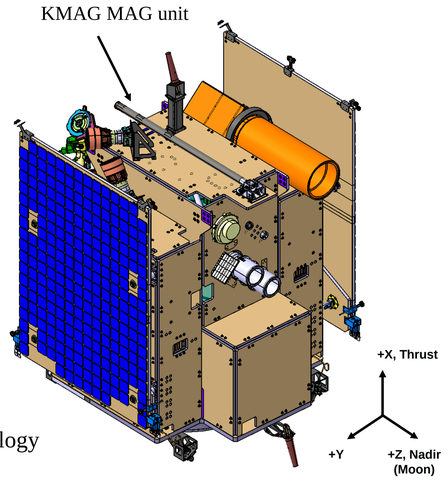

Figure 1. KPLO and KMAG MAG unit

KMAG

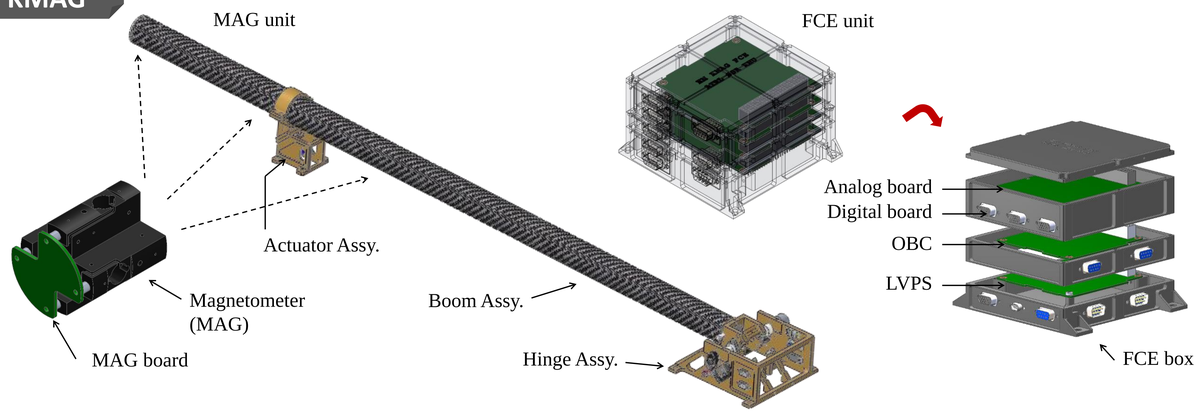

Figure 2. KMAG system configuration

- KMAG (KPLO-Magnetometer) measures the lunar magnetic fields during KPLO mission
- KMAG configuration
  - MAG (**MAG**netometer) unit: It consists of the boom Assy. (Assembly), actuator Assy. and hinge Assy. The three MAGs are located inside the boom tube of Boom Assy. And tube is 1.2 m long on CFRP (Carbon Fiber Reinforced Plastic) which has high strength to weight ratio. MAG unit is located outside top platform +X of S/C (spacecraft).
  - FCE (**F**luxgate magnetometer **C**ontrol **E**lectronics) unit: It is composed of OBC (On Board Computer for KMAG), LVPS (Low Voltage Power Supply), and two sensing board (Analog board and Digital board) with FCE box. FCE unit is located +Y shear wall of S/C.
- KMAG uses tri-axial fluxgate magnetometers which measures DC magnetic fields have ±1,000 nT measurement range and 0.2 nT resolution with 10 Hz sampling rate. Magnetometer have temperature coefficient of less than 0.1 %/°C and noise of less than 50 pT/sqr (Hz).
- Total mass budget of KMAG is 3.5 kg and power budget is 4.6 W. Housekeeping and the measured data will be generated total about 295.31 Mbit/day.

Table 1. KMAG specification

Item	Contents	
Science	Measure DC and low frequency perturbations of the magnetic field in the space and Moon	
Performance	Measuring range	± 1000 nT
	Resolution	< 0.2 nT at 10 Hz sampling rate
System	Mass	Total 3.5 kg
	Power	Input: +28 V (unregulated +24 ~ 32.8 V) Consumption: 4.6 Watt
	Interface	RS-422, 115,200 bps
	Operating temperature	KMAG Assy.: -55 °C ~ 70 °C FCE: -20 °C ~ 50 °C
Magnetic cleanness	< 700 nT at the inner-most MAG position in the boom	
Operation	Duty: 100%, Data generation: 295.31 Mbit/day	

Science Background

- Localized magnetic field (Magnetic anomaly) of lunar surface has been verified by Previous lunar exploration missions such as the Lunar Prospector (LP) and KAGUYA (SELENE).
- Even though past lunar missions have been supplied reasonable factors for the lunar magnetism, many puzzles still remained due to the limit of data.
- Research for lunar magnetic fields by the Kyung Hee University
  - Magnetic anomaly analysis and dipole model research for the Lunar surface
  - Statistical analysis for interaction with Lunar magnetic anomaly and Solar wind
  - Research of the Swirl with the Lunar surface
  - Magnetic field analysis in Crisium region

* Baek et al., (JGR, 2017) / Baek et al., (JGR, 2019) / Lee et al., (ICARUS, 2019)

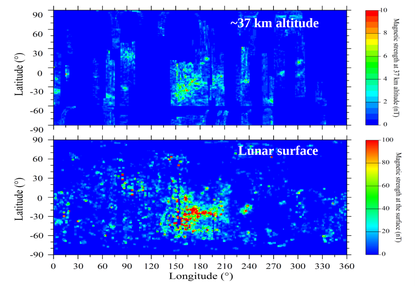

Figure 3. Distribution of lunar magnetic field from LP magnetometer data (~37 km altitude) (Top) and Electron Reflectometer data (Bottom) [[Lee, et al., LPSC, 2017]

Verification test

- **Function test**
  - Verified the electrical interface and operation with normal and boom deployment scenario
  - Developed the ground monitoring program to check the transmitted data
  - Long-term operation : 400 hr (EQM), 300 hr (FM)
- **Performance test**
  - Verified the measuring range and resolution level of KMAG (±1,000 nT, 0.2 nT respectively)
  - Check the scale range, linearity and noise level of each MAG

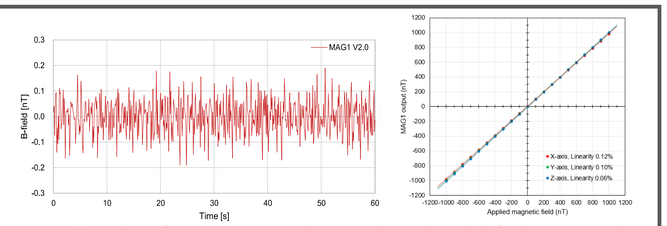

Figure 4. KMAG performance test results. Resolution level (left), linearity (right)

Table 2. Test results for each axis of each MAG

List / MAG #	MAG1			MAG2			MAG3			Req.
	X-axis	Y-axis	Z-axis	X-axis	Y-axis	Z-axis	X-axis	Y-axis	Z-axis	
Scale range [nT]	±1,600	±1,200	±1,600	±1,000	±1,100	±1,200	±1,300	±1,300	±1,300	±1,000
Linearity [nT]	1.16	0.96	0.64	0.71	0.54	0.73	0.34	0.62	0.35	5 (0.5%)
Noise [pT/$\sqrt{Hz}$]	3.57	2.83	6.18	3.75	10.09	3.01	-	-	-	50

Environment test

- **Radiation test (Total Ionizing Dose, TID)**
  - Location: Korea Atomic Energy Research Institute, Advanced Radiation Tech. Institute

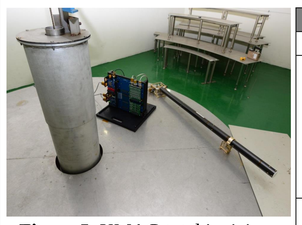

Figure 5. KMAG total ionizing dose test configuration

Table 3. TID test info. and result

List	Parameter	1st test	2nd test
Requirement	Dose	8.177 krad	9.321 krad
Irradiation condition	Type	Gamma-ray	
	Energy spectrum	1.17 and 1.33 MeV (Av. 1.25 MeV)	
	Total absorbed dose	1.28 x 10^4 rad	1.86 x 10^4 rad
	Absorbed dose rate	4.51 krad/h	3.54 krad/h)
	Irradiation time	2.83 h	5.25 h
	Dosimeter	Alanine dosimeter	
Irradiation room condition	Temperature	28.2˚C	23.8°C
	Pressure	~ 1 atm	
Dose (KMAG problem occurred)		12.8 krad	10.66 krad

- **Thermal vacuum test (T-VAC)**
  - Location: Korea Astronomy and Space Science Institute
  - Test for MAG unit will be conducted alternative thermal cycling test additionally.

Table 4. T-VAC test requirement and result

Item		Qualification	Test result
Number of Cycling		10	10
Soak Duration (Dwell Time)		2 h	2 h
Temperature Range	MAG Unit	-65°C ~ 80°C	-30°C ~ 60°C
	FCE Unit	-30°C ~ 60°C	
Temperature Transition Rate		≤ 2°C/min	0.24°C/min
Stabilization Condition		≤ 3°C/h	0.5°C/h
Pressure		≤ 10^{-5} Torr	10^{-5} Torr

- **Vibration test**
  - Location: Korea Automotive Technology Institute
  - Requirement: Sine sweep (Natural Frequency : > 140 Hz), sinusoidal, random vibration
  - Pre/post frequency shift (< 15%): pass & pre/post amplitude shift (< 20%): pass

Table 5. Vibration test result: 1st N/F list and pre/post frequency shift variation

Item	Test results (Hz)								
	Longitudinal (X-Axis)			Lateral (Y-Axis)			Vertical (Z-Axis)		
Test name	PRS	POS	Variation	PRS	POS	Variation	PRS	POS	Variation
FCE unit	818.7	801.7	2.07%	1621	1631	0.62%	470.2	459.1	2.36%
Hinge assy.	1555	1555	0%	1518	1536	1.19%	1560	1588	1.79%
Actuator assy.	556.2	502.3	0.1%	> 2000 Hz			1166	1138	2.4%
Boom assy. (end)	557.8	506.8	9.14%	168.7	165.7	1.78%	172.8	171.8	0.58%

- **Electromagnetic compatibility (EMC) test**
  - Location: Korea Institute of Industrial Technology

Figure 6. KMAG EMC test configuration

Table 6. EMC test result

Type	Item	EQM	FM
CE	UEMC 62101, Inrush current	NA	Pass
	UEMC62103, CE power lines	Pass	Pass
	UEMC62103, CE signal lines	NA	Pass
RE	UEMC 64102, RE AC H-field	Pass	Pass
	UEMC 64201, RE E-field	Pass	Pass

Future works

- KPLO program has done System Requirement Review (SRR), System Design Review (SDR), Preliminary Design Review (PDR), KMAG Critical Design Review (CDR), KMAG Manufacturing Readiness Review (MRR) and Pre-Ship Review (PSR).
- FM (Flight Model) development is in progress and it will be delivered by 1Q, 2019.