Mechanical Aspects of the Lunar Surface Magnetometer*

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Measurement of the weak magnetic fields on the moon requires an instrument of unique capabilities. Combined with the constraints imposed by integration into the Apollo Program, this imposed a complex and rigorous set of problems. This paper surveys the mechanical design of the Lunar Surface Magnetometer, the mission and environmental requirements which determined it, and the rationale whereby some of the problems were solved. Included are some intermediate phases of development.

I. Introduction

The Lunar Surface Magnetometer (LSM), Fig. 1, is one of the experiments comprised in the *Apollo* Lunar Surface Experiments Package (ALSEP). The package will be deployed on the lunar surface by astronauts during an *Apollo* landing mission and left in operating condition on the surface of the moon. The experiments are powered by a single radioisotope-thermionic generator, and all transmit data and receive commands through a common communications system.

Scientific objectives dictate the need for a three-axis magnetometer with sensitivity of ±0.2 gamma, a range of zero to ±400 gamma, frequency response dc, to 0.27 Hz, and initial positioning within ±3 deg in level and ±1 deg in solar azimuth. Capabilities include site survey of local magnetic field gradients, scientific measurements in three orthogonal axes, internal calibration, and engineering readouts of temperature, voltage, geometry, and status.

II. Mission Objectives

Observations by American and Russian spacecraft have confirmed that the moon has no significant internally generated magnetic field. Therefore, why build the LSM?

The LSM provides the means for obtaining several results that are not only of great scientific value but are impossible to achieve by other means. By examination of the topology of the interplanetary magnetic field as it diffuses through the moon, bounds will be set upon the lunar magnetic diffusivity, and its electromagnetic propagation characteristics will be examined, leading to conclusions as to its gross internal composition. The site

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survey, performed early in the mission, will investigate the existence of magnetically retentive materials in a sample of the lunar surface. Readings for a period of one year will provide data including (1) magnetic radiation density when the site is pointing toward or away from the sun, and (2) the lunar response to shock waves and discontinuities associated with the solar wind (which generates interplanetary magnetic fields).

Another important set of results will be measurements of the earth's magnetic field. As the moon intercepts the earth's magnetospheric tail each month, sets of readings will determine its intensity, shape, and direction. Electrical currents in the magnetic plasma will also be detected by determination of the vertical component of the curl of the magnetic field; a nonzero curl will indicate the presence of currents according to Maxwell's equations.

III. Design Constraints

The LSM has three ranges of magnetic measurement: zero to ±100, ±200, and ±400 gammas. For comparison, a typical midlatitude surface reading of the earth's magnetic field would be 50,000 gammas. Sensitivity requirements imposed on mechanical design a magnetic cleanliness level of less than ±0.2 gamma at the sensor heads. Combined with a weight limitation of 18 lb, including some 2600 electronic parts, magnetic requirements necessitated careful materials selection as well as design configuration.

The lunar surface temperature ranges from −173 to +133°C. However, because the electronics dictated an operating range of −30 to +65°C, a sophisticated thermal system was required. (The sensor heads, for example, need 2-W heaters, but even these were a magnetic problem; they were made up of two coils each, wound to opposite hand so that their magnetic fields cancel.)

Because the LSM was allotted only 10 × 15 × 26 in. in the ALSEP storage bin on the lunar module, the sensor arms had to be double-hinged and folded. The resulting configuration complicated the transmission of forces to flip and gimbal the fluxgate sensors as well as

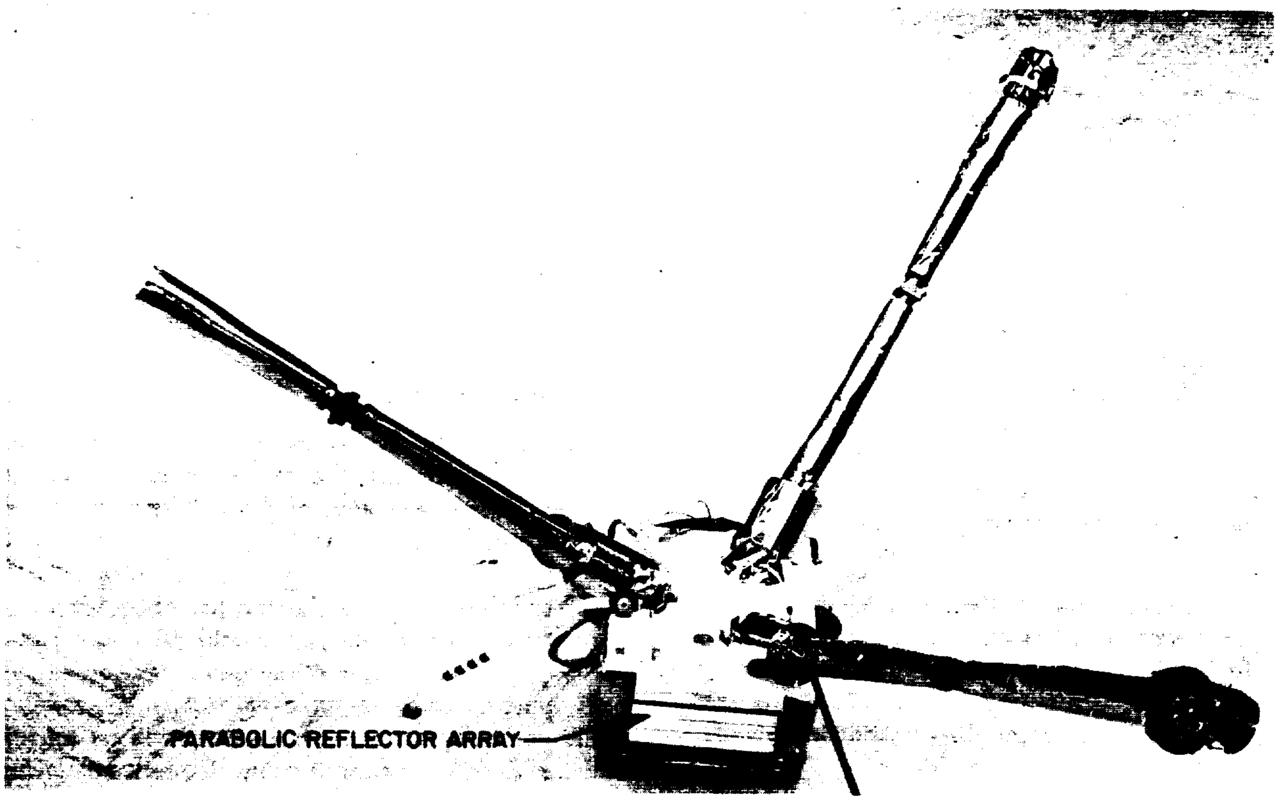

Fig. 1. LSM deployed

the transmission of electrical signals. These requirements also dictated a weak structure in terms of withstanding the stresses accompanying launch of the *Apollo* vehicle.

The three-arm configuration shown in Fig. 1 was dictated by the necessity for the sensors to comprise an orthogonal three-axis system. The three-foot arm length provides sensor/sensor separation sufficient to permit magnetic field detection among the surrounding lunar debris and also maintains the magnetic bias of the LSM electronics and motors within limits. The support legs provide magnetic and thermal isolation from the lunar surface.

Figure 2 shows the resultant electromechanical system, called the gimbal flip unit (GFU), which includes the three sensor head arms, the sensor heads (not shown), and the drive and mechanical programming assemblies

Fig. 2. LSM gimbal flip unit

which operate the drive cables actuating the fluxgate sensors and gimbal mechanisms. Also included in the GFU are the electrical level sensor, support legs, temperature detectors, and (not shown because they are located above the thermal coverings), a solar shadowgraph for azimuth orientation and a visual bubble level.

IV. Operation

A description of the operations can be followed by means of Fig. 3. The motor gearhead (1), which powers the drive cables, is a conventional-looking size 7 instrument motor gearhead, but it had to be specially developed because of magnetic cleanliness requirements, sealing for lubrication retention through the year-long mission in the lunar vacuum, power constraints, and reversing and torque-limiting requirements.

In the science operating mode, readings are alternated every 12 h with short flip-calibrate sequences. An internal LSM program schedules the activity, alternately reversing the motor each cycle. The motor run is timed so that the primary arm driver (7) moves the primary toggle arm (8) to apply tension to the double toggle spring (11) until it reaches a state of tension which overcomes the restraining forces on the secondary toggle arm (10). The secondary toggle arm then snaps away from one limiting stop (stops not shown) to the other. Rotational motion is transmitted through the output shaft (9) to the two independent (end-tied) cables (22), which flip the sensor (18) against the appropriate 0- or 180-deg stop (stops not shown). Several other designs were considered, but fail-safety was paramount; with this configuration, failure of almost any single part cannot leave the sensor at a position other than against the 0- or 180-deg stop. The LSM can still make valuable readings if it is limited to only one of these positions.

A special mechanical program is needed for the site survey operating mode early in the mission. The LSM starts its mission with each of the three sensor heads gimballed to a "wrist" movement 90 deg from its later position in order to perform the site survey, which requires each arm in turn to assume the 0-deg flip position

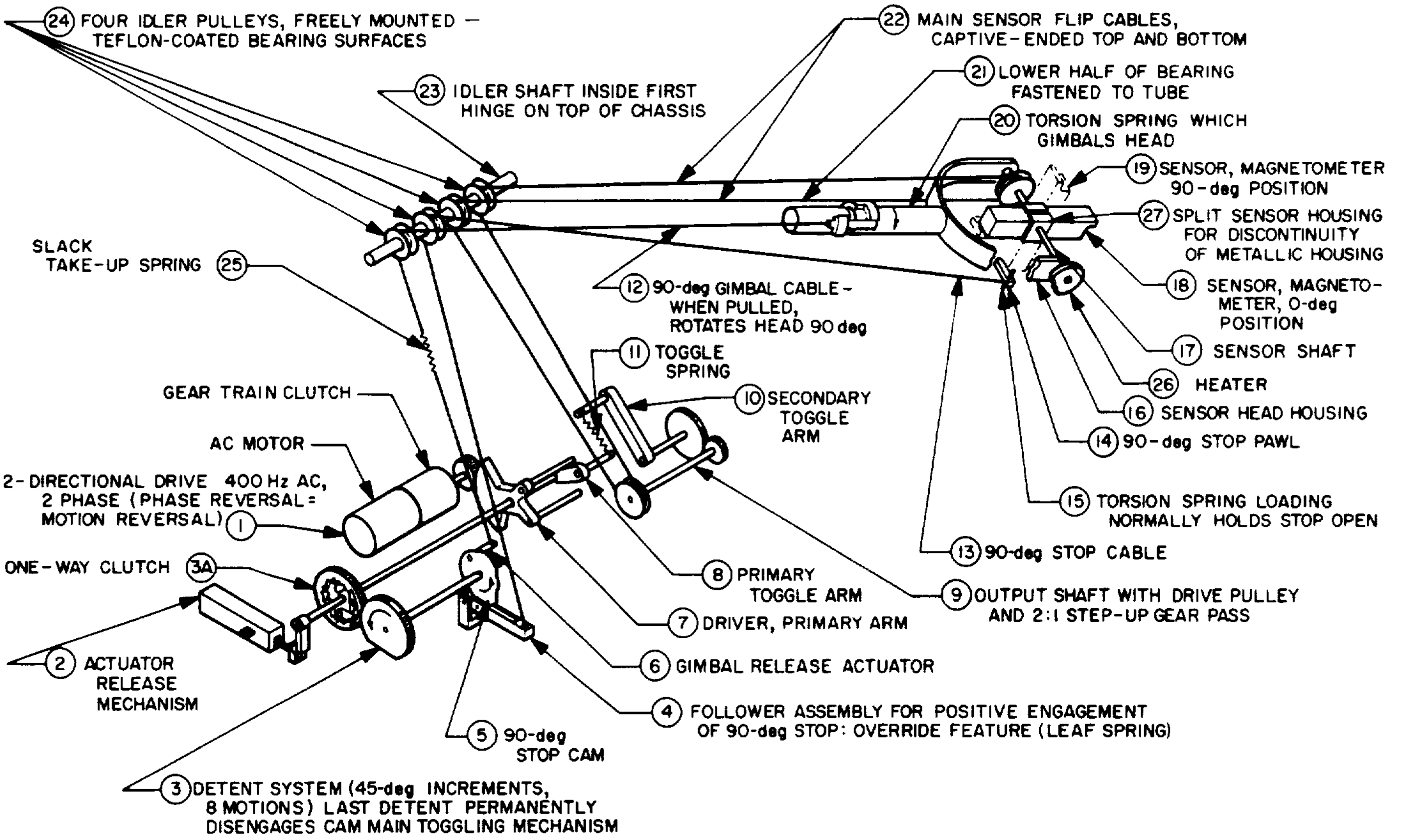

Fig. 3. Schematic of the gimbal flip unit

while the other two arms have their sensors in a position parallel to the arm being surveyed. Flip-calibrate operations precede the site survey, but during half of these movements the primary toggle arm (8) is not turning the detent system drive gear (3), because the electrical program is reversing the motor at each actuation, and the one-way clutch (3A) is slipping. However, at intermediate actuations, the one-way clutch is turning 3, and the gear ratios are such that this movement is 45 deg of the 90-deg stop cam (5).

The shapes and initial positions of these cams, one on each arm, are such that, after the initial flip operations, the lobes of the cams program the site survey event sequence. First, arm X is flipped to 0 deg, and arms Y and Z are at 90 deg. This is accomplished by cam rotation at arm X without tripping the follower assembly (4), whereas cams Y and Z depress 4, pulling the 90-deg stop cable (13) against the torsion spring (15), and placing the 90-deg stop (14) in the path of the fluxgate sensor. The survey about arm Y requires Y to be at 0 deg, but, in order for the X and Z sensors to be parallel to arm Y, they must be at 90 deg and Z must gimbal. To survey the Z arm plane, Z is at 0 deg, X is gimballed and at 90 deg, and Y is at 90 deg and gimballed. Gimballing is powered by torsion springs under each sensor head, and the energy is released by the gimbal release actuator (6), through the gimbal cable (12). The gimbal movement is restrained by a stop which also maintains proper sensor head position.

When the site survey operation is completed, the detent gear (3) has been turned so that the driver (3A) no longer engages it. Thus the 90-deg stop and gimbal are permanently disabled. After completion of site survey, the LSM alternates between the science and flip-calibrate modes, which consist of sequences of 0- to 180-deg flipping, through the year-long mission.

V. Typical Intermediate Phases of Development

The LSM went through design iterations of almost every critical assembly. For example, prior to receipt of *Surveyor* data, it was thought that launch of the *Apollo* Lunar Module from the lunar surface would result in clouds of particulate matter which would coat all horizontal surfaces of the LSM, changing their thermal characteristics. The first set of thermal controls therefore consisted of shades deployed several inches above the LSM components. Because results from the *Surveyor* program showed that substantial LSM surface contamination with particulate matter is extremely unlikely, the thermal design was redirected toward the parabolic reflector array (PRA) as shown in Fig. 1. Each of the two PRAs consists of three thermal control surfaces and associated parabolic reflectors. The thermal control surfaces emit heat during the day, but, in conjunction with the reflectors and sun-shades, prevent overheating. Together with the insulation, they also prevent excessive heat loss at night.

VI. Testing

Several test programs were conducted at various levels. Assemblies were operated in thermal-vacuum chambers, and other components required evaluation for magnetic cleanliness, which was done in Mu metal flux tanks. Five materials were tested in thermal-vacuum environments to determine the best cable material. The visual bubble level was an unknown quantity; no manufacturer either knew or cared about their performance in vacuum or extreme temperatures. It was necessary to buy the test samples, go through qualification test cycles, dictate modifications, and then retest the production lot.

LSM system level tests were followed by ALSEP interface and integration tests at Ann Arbor, Michigan, by the Bendix Corporation, the ALSEP prime contractor. The test sequence was successfully completed in December 1967.

VII. Lunar Deployment Simulation

Astronaut deployment of the LSM also had to be integrated into the design with deployment activities maintained within the limitations of the suited astronaut. To release the LSM from its attach points, a simple handle was developed, with linkages and cables to quick-release mechanisms, so that a single pull also releases the stowage bracketry and foam padding shown in Fig. 4. The LSM is hand-carried to its operating site, which, dictated by magnetic considerations and local topography, will be within 50 ft of the communications system. As it is carried, a flat communications cable, permanently connected at both ends, is unreeled. After locating a suitable site, the astronaut unfolds the legs, which are positioned by detents. The LSM is positioned in azimuth by means of the solar shadowgraph, and then the legs are levelled by application of a tool to the shafts of worm screws/gear segments controlling each leg. The arms are unfolded, the hinges being detent-controlled.

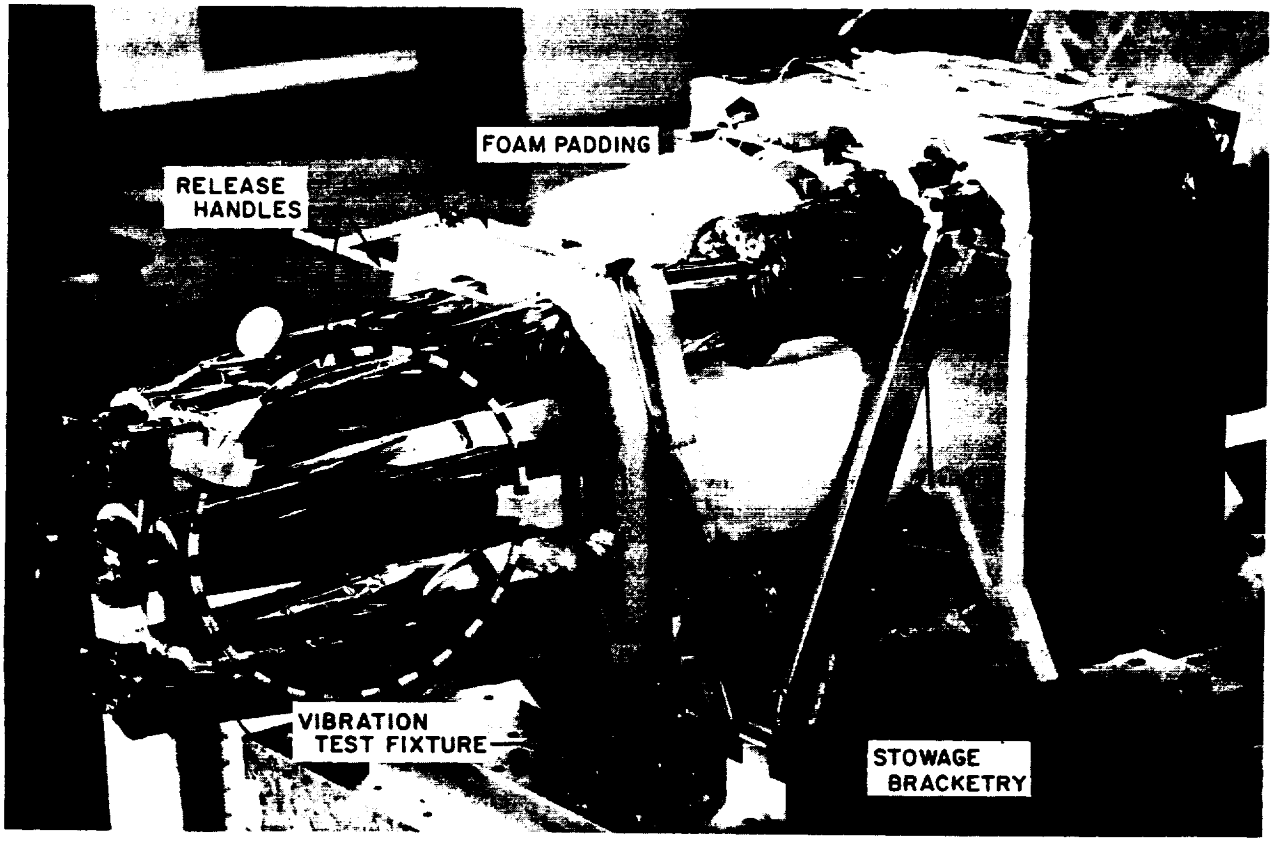

Fig. 4. LSM in stowed configuration

A series of astronaut deployment tests was conducted by the Bendix Corporation at Ann Arbor, Michigan, and by the National Aeronautics and Space Administration at the Manned Spacecraft Center at Houston, Texas, in facilities simulating the lunar surface. These tests identified the requirements for several design and operational changes.

VIII. Conclusion

The LSM program reached state-of-the-art levels in magnetometer design, materials applications, and in mechanical and thermal analyses. Many specialists contributed their expertise, and a close correlation between analytical and test results was achieved.