

Design of Superconducting Gravity Gradiometer Cryogenic System for Mars Mission

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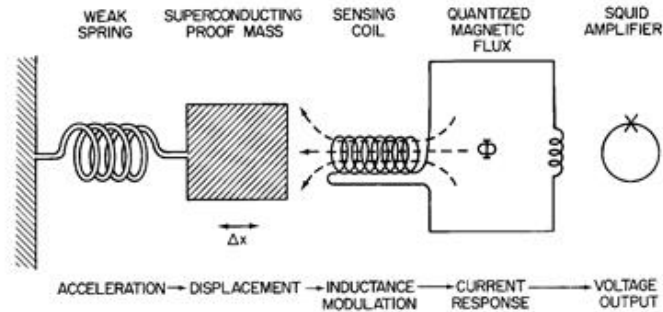
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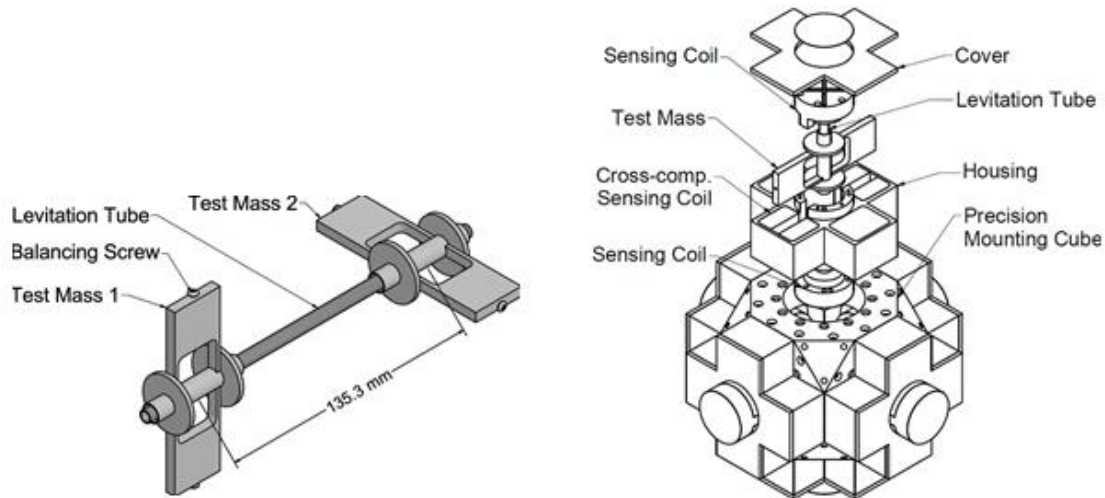
Science Purpose

- Superconducting gravity gradiometer measures static and time variation gravity files with very high precision
 - First mission to measure Martian gravity using high precision gradiometer
- Measurements of gravity field will help to understand the internal structure of the planet, how the solar system evolved, and why Mars as it is today
 - Map the gravity of Mars in greater detail (higher resolution)
 - Time-variation of the Mars gravity field mapping will help to understand climate on Mars
- Past missions to measure gravity
 - GRAIL (Moon 2011): Two spacecraft with satellite-satellite tracking (NASA/JPL);
 - GOCE (Earth, 2009) : Electrostatic Gravity Gradiometer (EGG, Most accurate so far by ESA);
 - GRACE (Earth, 2002): Two spacecraft with satellite-satellite tracking (NASA and DLR).
- SGG measures Mars gravity field with high fidelity
 - Two magnitudes more accurate than EGG (GOCE)
 - Ability to accommodate vibration noise that is 100 times higher than EGG
 - Minimum coverage of surface is 50 km, which is 100 km for EGG.
- Current status of SGG
 - Developing TRL 4 instrument at UMD (Prof. H. J. Paik)
 - Spacecraft configuration & Cryogenic Cooling System

Instrument



(a) Principle of superconducting accelerometer



(b) Two test masses levitated around a tube

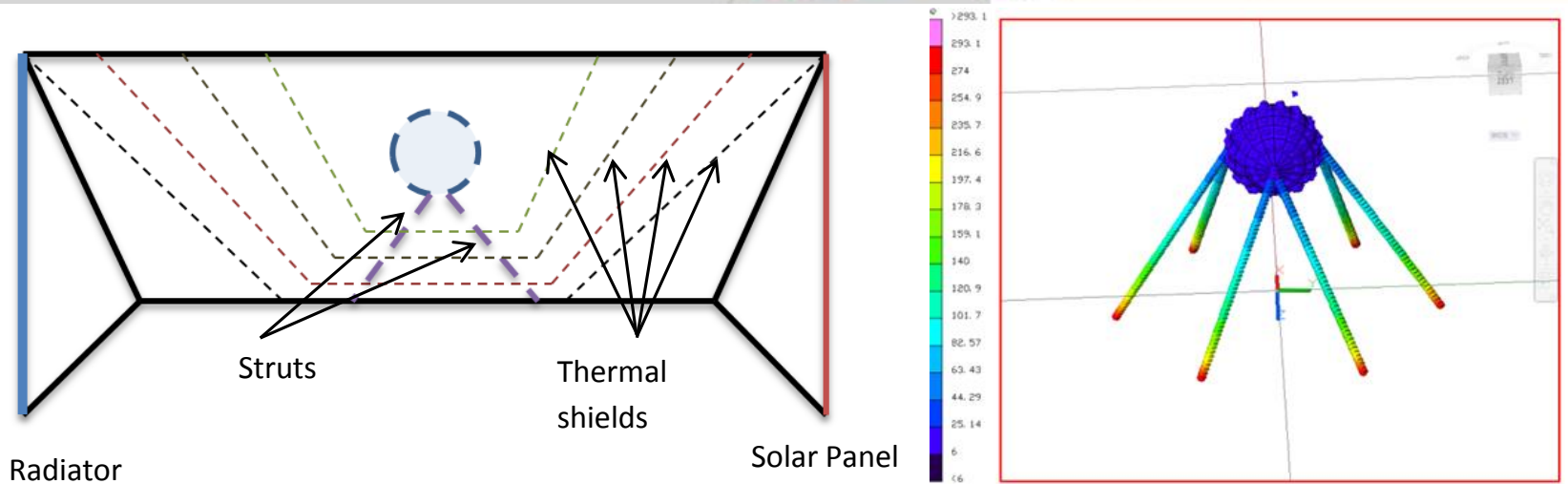
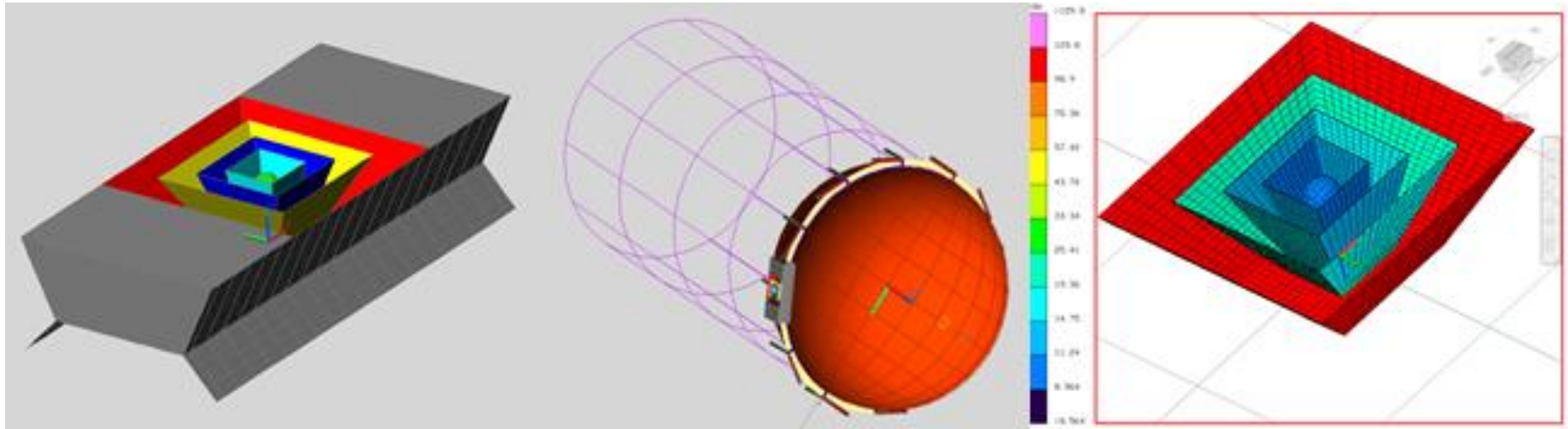
(c) Six test masses form a tensor gradiometer

Requirements

The driving requirements for this design are listed below.

- The SGG operates with the highest efficiency at ≤ 4 K, and it operates with reduced accuracy at any temperature below 8 K.
- In general, it takes 6-8 months for spacecraft to travel from Earth to Mars, and another 5-6 months for insertion into the low-altitude mapping orbit using aerobraking. For example, this was the experience of the Mars Reconnaissance Orbiter (MRO).
- The SGG should be precisely located at the center of gravity of the whole spacecraft.
- The SGG instrument is sensitive to vibration. Linear acceleration from the spacecraft shall be less than 10^{-6} m/s²/Hz^{1/2}, and angular acceleration shall be less than 10^{-5} rad/s²/Hz^{1/2} during the operation. The instrument measures at frequencies below 10 Hz.
- The operating orbit shall be sun-synchronous, face-on to the Sun to minimize thermal variations, and the mean altitude is assumed to be 200 km.
- The mass of spacecraft shall be less than 500 kg, and the power shall be less than 300 W.

Spacecraft Configuration



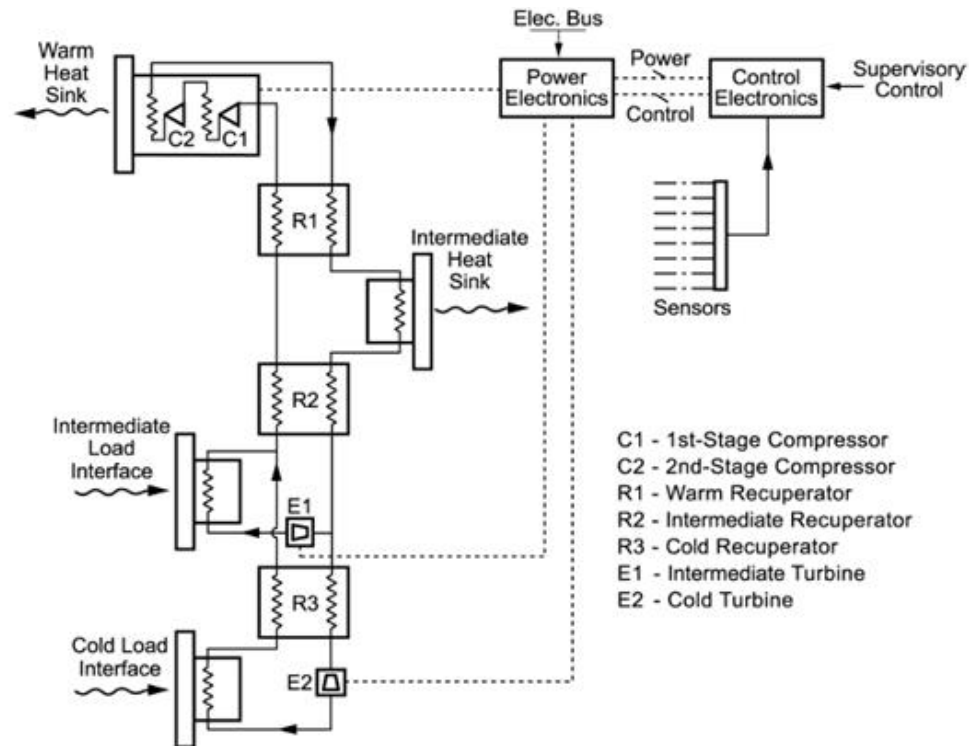
Cryogenic System Design

- Passive cooling
 - Shields
 - Low thermal conductivity struts
- Active cooling
 - Two stages Turbo-Brayton cryocooler
 - 10K Adiabatic Diamagnetic Refrigerator (ADR)

Shields	Temperature (K)
Shield 4 (outer layer)	171
Shield 3	70
Shield 2	28
Shield 1 (inner layer)	10

Cryocooler

- Two stage Turbo-Brayton cooler
 - Zero vibration at low frequency

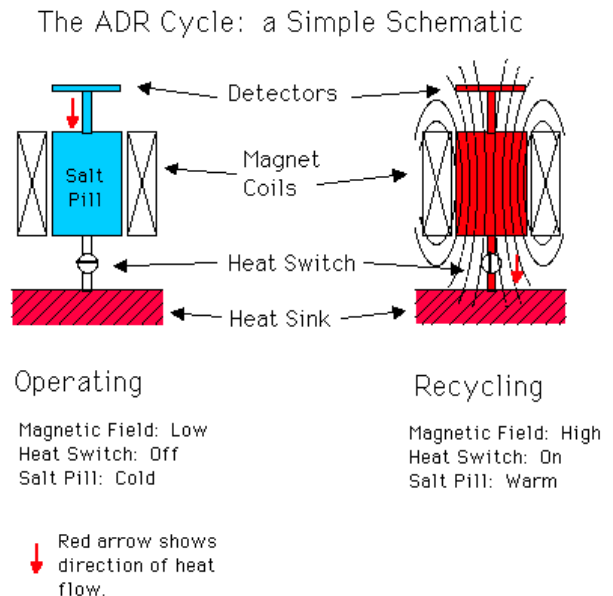


ADR

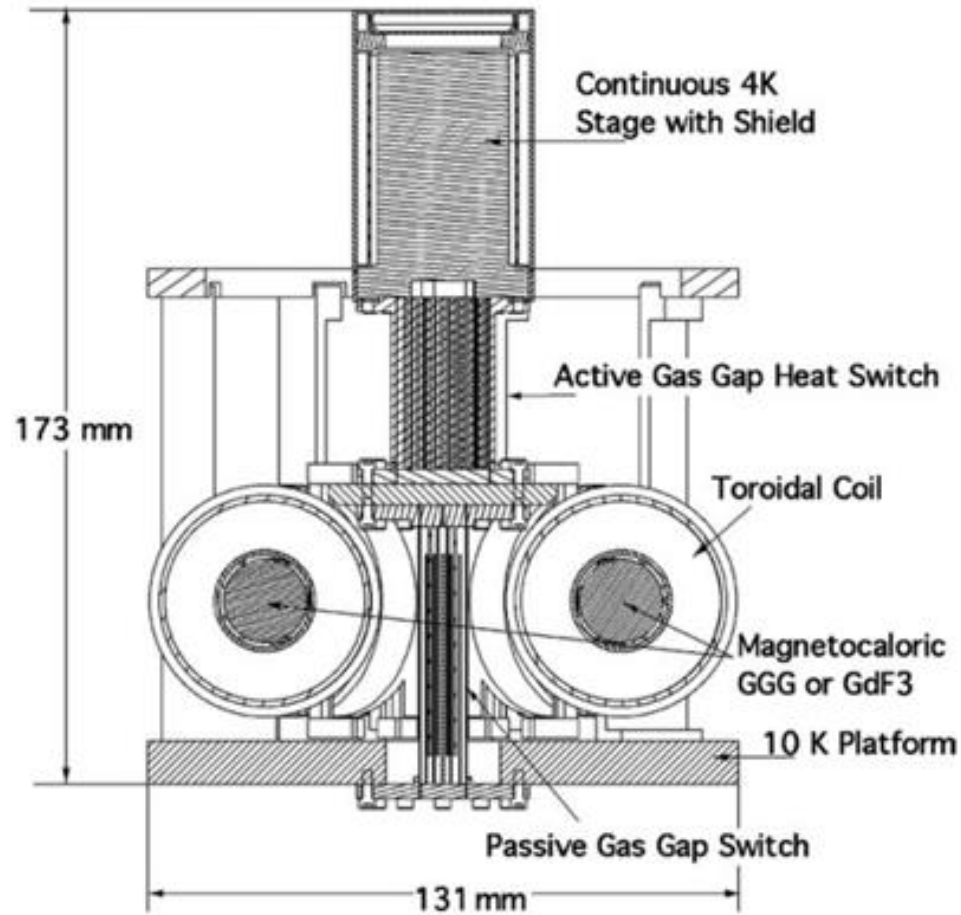
The ADR operates in a cycle.

1. Warm up. The magnetic field is turned on full. The salt pill temperature rises.
2. Dump heat to thermal sink. The heat switch is turned on. Heat flows from the "hot" salt pill to the thermal sink.
3. Cool down. The heat switch is turned off. The magnetic field is dropped rapidly. The salt pill temperature drops.
4. Cold part of cycle. The cold salt pill cools whatever it was designed to cool. (In the case of XRS, that would be X-ray sensors.)
5. Repeat Return to step 1 and start over.

Pass Mission:
Astro-H (50mK)



10K ADR



Results

Instrument temperature	6 K		4 K	
Cooler(s)	Reversed Brayton 68 K/6 K two-stage cryocooler		Reversed Brayton 68 K/10 K two-stage cryocooler with ADR from 10 K to 4 K	
Cooling load	68 K	2000 mW	68 K	2000 mW
	6 K	100 mW	10 K	200 mW
			4 K	10 mW
Power	68 K 6 K	160 W	68 K 10 K	200 W
			4 K	50 W
Mass	26 kg		36 kg	

Future Work

- Increase instrument TRL
- Increase Cryocooler and ADR TRL
- Mission Design
 - Requirements
 - Vibration requirements
 - Power and mass