Mercury Robotic Payload

Contract No. 16882/02/NL/SFe

Project Abstract

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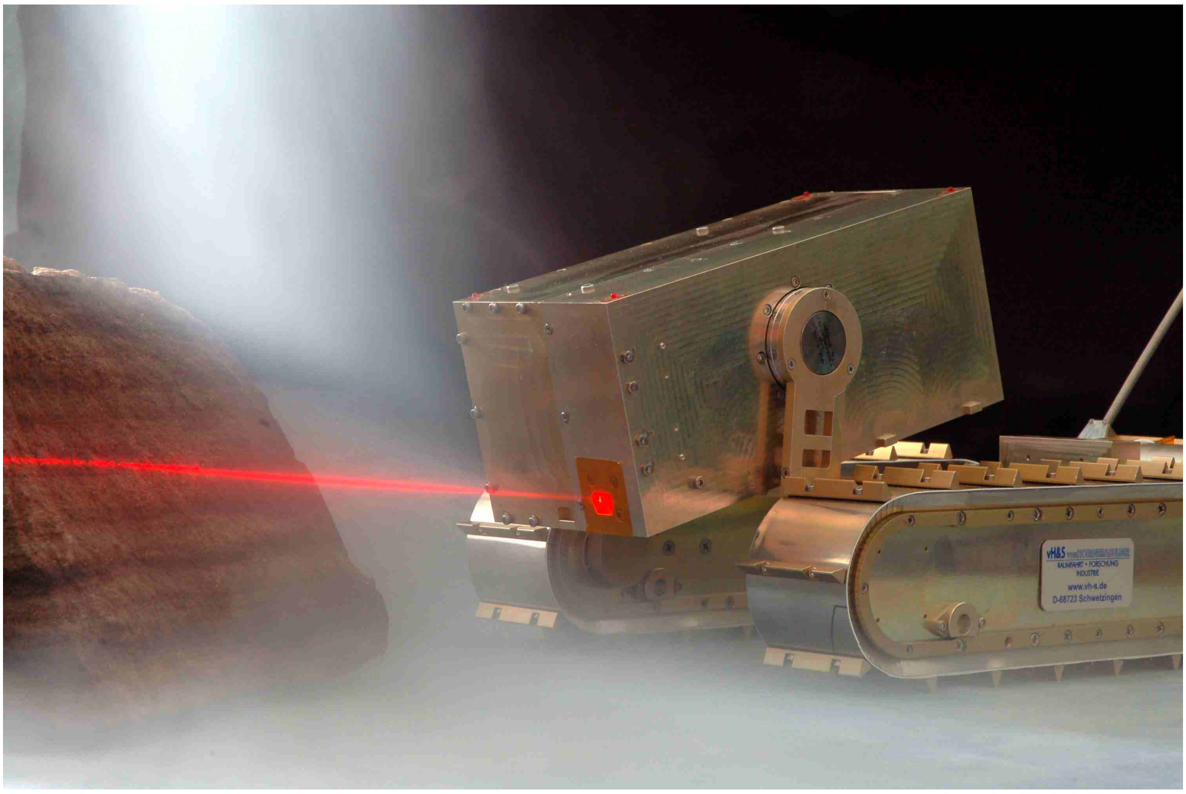

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1 Introduction

The Nanokhod Rover type has a development history starting in 1990's during which von Hoerner & Sulger GmbH has taken the leading role. The original Russian concept has been developed to accommodate instruments and prototype versions have been tested on soil stimulants. However it is only with the MRP project that it has been possible to make a practical design to withstand the tough requirements of a flight. Having realised a design meeting the requirements, a hardware model has been manufactured to an engineering level which is suitable for environmental testing of vibration, shock and thermal vacuum to the extreme requirements of a mission to Mercury. The design and manufacture of the MRP Nanokhod Rover is described in this abstract.

2 The Mission to Mercury

The basis of this project was to produce a well matured Rover model in preparation for the Bepi-Colombo Mission. At this time a Lander was being seriously considered and the Nanokhod type rover has been selected to provide local mobility around the landing site. Unfortunately the Rover along with the Lander were cancelled from the Bepi-Colombo mission but it was decided to proceed with the development to better understand and solve detailed technical problems of a real implementation in preparation of future missions.

The expected profile of the Rover mission would take place after a journey of up to 4 years from the earth. At this point the Lander system will descend to the planet surface. Deceleration of the lander is performed using chemical propulsion due to the lack of atmosphere. The landing site for this mission is on the night side of the planet where the extreme thermal environment is simplified by the removal of the sun's radiation. Despite this the environment remains extreme, coupling a high vacuum with surface temperatures estimated to be in the region of -180°C. Because of this, all energy must be supplied chemically assuming that a nuclear solution is politically unacceptable.

Once deployed, the MRP Nanokhod rover will operate for a period of between 7 (baseline) to 14 (extended) earth days during which time the landing site would remain on the nightside due to the 88 day length of the sidereal Hermean day. The rover will communicate and be powered by the lander via tether of at least 50m allowing the rover to explore an area of at least 10m radius from the lander.

The MRP Nanokhod shall be able to move across the fine regolith surface with a speed of 5 metres/hour and negotiate steps 10cm high and trenched 10cm wide. It shall make at least 1 scientific observation per 24 hours with its three instruments: Microscopic camera (MIROCAM), APXS and Mössbauer Spectrometers.

Due to communication constraints between the lander and Earth the rover shall operate near-autonomously with a single communication period once per day.

3 Design Drivers

The main design driver in the design is the mass of the whole system. Ultimately this is derived from the fact that the launch fuel cost for each kilogram landed on the planet surface is very high due the difficulty to reach Mercury's orbit and the need of chemical propellants to actually land.

It is obvious that these items scale directly with payload mass and thus the mass of the complete lander system must be minimised in order to make the mission feasible. The low mass of the lander system dictates that its structure shall be limited in it size which results in a strict volume requirement for the Rover.

Opposing these mass and volume requirements is the need to make a practical system which will not only has the strength to undergo the vibration and shock environments dictated by the above but will also allow for a practical rover design which includes the required instrumentation and functionality but also facilities to allow AIV of a future flight model. The next significant design driver is the energy consumption of the Rover system. This is also related to the mass issue as all energy requirements of the Lander and thus the rover itself must be carried by the Lander itself in the form of batteries. For a given mission duration, the less energy consumed by the system the less battery capacity is required and thus battery mass is reduced.

Activity	Description	Duration		Energy Consumed	
		Hours	% Total	Wh	% Total
Checkout	System test on lander	8	5%	13	6%
Deployment	Exit Lander perform first measurement cycle	9	5%	17	9%
Movement	Move between two measurement sites	14	8%	76	38%
Measurement cycle	1 measurement with each instrument	57	34%	95	47%
Idle	No activity	111	66%	0	0%

Table 1: Operational Analysis of a 7 day mission

By looking at the mission profile it can seen that for a baseline mission the rover will only spend on average 12 hours in the 7 days performing locomotion. This assumes that PLC movements for instrument deployment are relatively insignificant in duration. In comparison, the times required to perform reasonable measurements with the spectrometers can expected to be approximately 2 and 3 hours minimum per measurement for APXS and MIMOS respectively - or in total greater than 35 hours during the 7 days. It should also be noted that whereas the locomotion duration has a hard limit defined by the length of tether the rover carries, measurement quality is improved with longer measurement durations and this may be requested by the scientist during operations. This is illustrated with mission scenario results from the system design studies in Table 1.

With this in mind the system design should attempt to reduce the energy consumption during measurement operations to a minimum and when the rover is idle it should not consume any energy at all. This dictates that the rover relied on passive thermal control and it is expected that it will reach the surface temperature of -180°C when not in operation.

4 Design Overview

The main components which are generic to all Nanokhod rovers are (see Figure 1):

- Two locomotion units (LU) enclosed by walls and the driven caterpillar tracks which provide the method of locomotion
- The tether unit (TU) which rigidly attaches both locomotion units and holds the spools from which the tether wire is deployed

- The payload cabin (PLC) containing the instruments
- Arms connecting the PLC to the LU giving the PLC two degrees of freedom allowing the instruments to place next to sample sites and for the PLC to act as an extra limb for negotiating obstacles.
- Four internal drive units used to drive the caterpillar tracks and position the arms relative to the LU and the PLC.

Externally the new design does not display significant differences from previous models. The main items to note are that the TU has been designed to give greater ground clearance to prevent a "bulldozing effect" of regolith that occurred in previous models. Similarly the tether guides are angled upwards to prevent both regolith entering the tether guides or the rover running over the tether when reversing. The modifications have meant that the current design loses its top/bottom symmetry allowing full operation in both orientations. In reality, any operational scenario would avoid any instances where the rover is at risk of rolling over and even if it did, the rover still has the ability to right itself by lifting the tracks over the PLC.

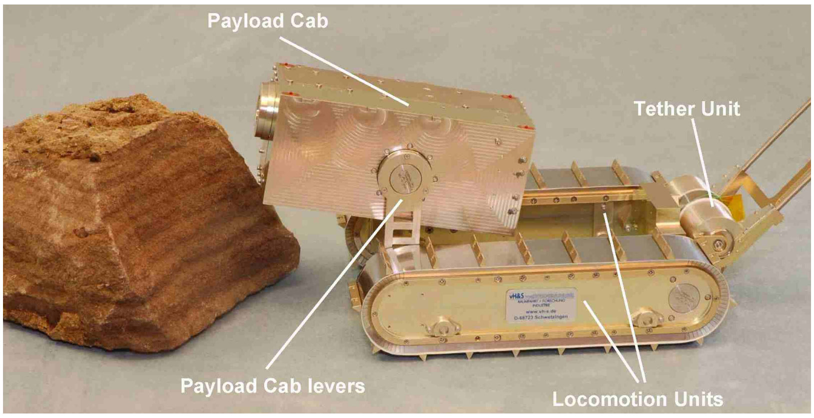

Figure 1: Generic Nanokhod rover components

The other noticeable addition is facilities for accommodation of the rover in flight which had not been fully considered previously. The sealing system between the LU walls and the track are delicate and would experience damaged from the landing shock. The new stowage concept uses four cups on each LU which are clamped by the conceptual hold-down device. The PLC is held separately to prevent damage to the arm mechanisms with teeth located on the base of the PLC (Figure 2). The tether guides also feature a spring loaded deployment device so they can be held against PLC during flight and landing.

Internally the new design differs significantly from previous models both electronically and mechanically. Mechanically the overall structure has been upgraded to withstand the rigours of vibration and shock with the inclusion of four rigid yokes in the LU's. Analysis has been performed on all components to ensure that they are compatible to the mechanical and thermal environment.

A completely new drive system has been implemented based on a similar concept for all four drives within the rover. Due to the high vacuum environment it is not possible to use standard DC motors for extended durations and so the Faulhaber AM1020 stepper motor was selected as the motor for the drives. This motor had been previously tested and selected during the RTPE project and although stepper motors have significant disadvantages it was the only available device at the time which met both the volume and the torque requirement needed for operation on both Mercury

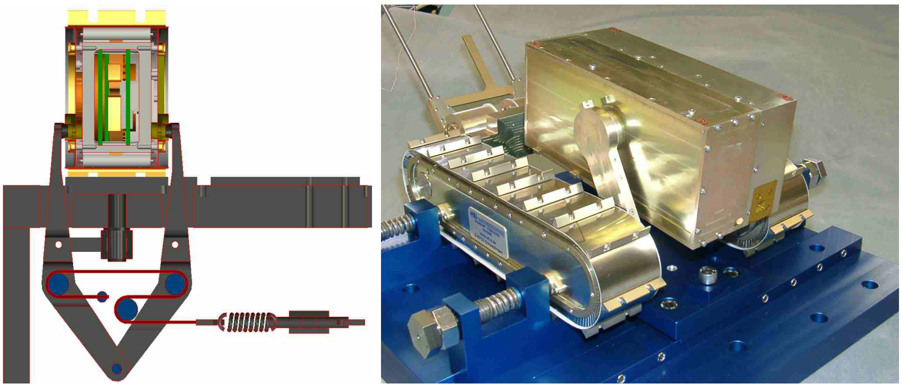

Figure 2: Left; LU conceptual holddown mechanism; Right: mock up for vibration testing (PLC released & raised)

and Earth. The motor itself is attached to 64:1 planetary gear in front of a crown and pinion gear stage. The output stage is a miniature harmonic drive whose input is coupled directly to the crown gear. The output is taken either from the flexspine or the circular spine depending if it is a track or arm drive. Dicronite dry lubricant was used on both the Harmonic Drive and crown gear the application of which had been tested at Harmonic Drive AG. The other components were supplied pre-lubricated with MOS2 by the manufacturer.

Electronically the system is has been partitioned into a number of nodes each of which perform a distinct function. The nodes are connected using a 9 way bus containing both power and a I2C communication link which is selected that allows for reliable and simple communication over the temperature range. Power for the drive system nodes is supplied by a 28V line which is also controlled by the tether interface node (TDU). When the power is removed from this line all drive units are powered off minimising the power consumption during instrument operations. Central to each node is a piece of digital logic which controls each node and provides is data interface. For a flight model this would be implemented in a common ASIC which contains all the functionality required for each node. In the current model this has been simulated using a SOC microcontroller whose code is common to all nodes.

5 Manufactured Rover

Figure 3 shows various aspects of the manufactured rover. Despite efforts to simplify the integration process, successfully assembling the rover is a slow and careful process. The small geometrical size of the rover meant that all components had to be miniaturized especially the fasteners which required very careful handling in order that they are located correctly into position without risking damage to the thread. All other operations such as component positioning, cleaning, gluing and lacing of harness became extremely complex to perform due to the lack of space in the half assembled rover. The size also made it impossible for more than one person to perform work on it simultaneously.

Another factor that caused problems during the integration of the rover, is the difficulty to perform any inspection once a unit (LU, PLC or the TU) had been fully assembled. Although it initially intended to be able to assemble and test a complete LU on a single wall before its final closure, this was not possible due to harness constraints. The use of more miniature connectors in the electrical system would solve this problem, however the number was minimised in the design largely due to the high cost of the miniature connectors.

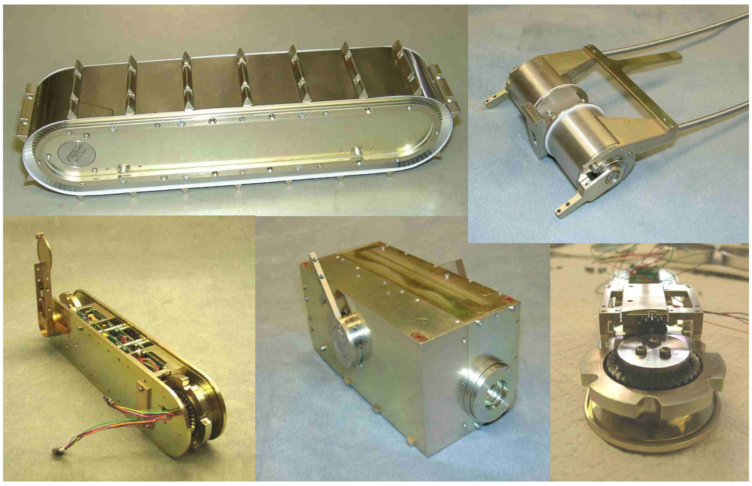

Figure 3: Manufactured MRP components

Parameter	Unit	Requirement	Manufactured	Notes
Stowed Length	mm	240	232.0	
Stowed Width	mm	165	162.2	
Stowed Height	mm	65	67.4	Extra height due to protruding LED's which are raised for better visibility
Rover mass	g	1800	1820	Manufactured mass includes central subsystem PCB which is not include in requirement
Instrument mass + central subsystem	g	900	550	From GIPF project and measured value does not include central subsystem mass

Table 2: Requirements versus manufactured values

Table 2 compares the design values with the actual values of the rover system. The whole rover system is within the required mass constraint when taken in conjunction with the GIPF instruments. The mass not displayed in the table are items which are accommodated on the lander. The requirements budgets 500g for the mass of these items. Manufacture of the hold down device was not with in the scope of the project and the EGSE interface electronics is not totally representative of a flight system as it contains additional components and an external case. For comparative purposes EGSE interface has a mass of 414g including case but for a flight version the card would be incorporated within the lander subsystem. For the hold down device a rough estimate of mass from conceptual design is in the region of 900g - the significant increase of weight is required to successfully support the rover during shock conditions: A reduction of this mass may be achieved with more information about the landing scenario and also by incorporating the mechanics within the lander structure itself.

6 Functional Tests

After integration, a sequence of functional tests was performed to ascertain whether the rover met the operational requirements laid down at the start of the project. Table 3 summarises the results.

Requirement	Description	Status	Notes
Mobility – reverse	Reverse by at least its own length	Fulfilled	
Mobility – spot turning	The rover shall perform a spot turn >90°.	Fulfilled	
Mobility - obstacle	Climb a step of 0.1m or traverse a ditch 0.1m deep	Fulfilled	
Mobility - speed	Maximum traverse speed of 5m per hour	3.06m.h^{-1}	Limited by planetary gear
Payload Cab movement	Orientation of PLC apertures to a surfaces at inclinations from horizontal to vertical	Fulfilled	
Payload Cab contact	The Rover shall push the payload cab against a hard surface with a force > 1N	Fulfilled	
Rover – peak power	The rover shall consume no more than 6W peak power from a 28V source	Fulfilled	See text

Table 3: Summary of Functional Test Results

The rover fulfils all requirements except the speed requirement which is limited by the maximum rpm allowed by the planetary gear. However the reduction of maximum speed still allows the design to meet the input requirements of the mission scenario as presented in Table 1 which uses the slower design speed in its calculations.

During tests the current consumption during forward locomotion was measured to be at peak 190mA (5.3W) measured on the lander side. This value is a maximum value and includes approximately 40mA used by two controllable heaters which provides local component heating of the driver circuits which may be required for starting at the most extreme temperatures. During instrument operations the rover subsystem will only consume approximately 17mA ($< 0.5W$). These values are less than those predict from the rover design which were used in the energy usage calculations in Table 1 and results in a predicted total energy consumption for the baseline mission of 202Wh. This compares to a requirement that the total energy consumption for the baseline mission shall be less than 265Wh.

7 Conclusion

Although a mission to the Mercury surface is currently unlikely, the challenging nature of the Mercury environment makes the developed technology to be applicable with moderate modifications on a variety of other planetary bodies.

The Moon has now become very popular in consideration for proposed visions. The night side environmental conditions of the Moon is similar to Mercury and would allows easy adaptation of the current concept. For a dayside landing the new Nanokhod model is still very applicable although new attention would need to be given to the thermal design.

The MRP Nanokhod rover is huge advance towards a practical flight model despite limited resources that were available. Solutions are available to the current open issues and its hoped that these will be implemented in the immediate future allowing the Rover to be subjected to environmental testing .