MOLE PENETRATOR 'KRET' FOR LUNAR EXPLORATION

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INTRODUCTION

Mole devices are low velocity, medium to high stroke energy but low power, self-driven penetrators, designed as a carrier of different sensors for in situ investigations of subsurface layers of planetary bodies [2]. The maximum insertion depth is limited by energy of mole's single stroke and soil resistance for the dynamic penetration.
A mole penetrator KRET (Fig. 1) has been de-signed, developed, and successfully tested at Space Research Centre PAS in Poland [5]. KRET design takes advantage of the MUPUS penetrator [3] (a payload of Philae lander on Rosetta mission) insertion tests knowledge [4]. The parameters of the mole KRET are listed in the Table below.

Outer diameter [mm]	20.4
Length [mm]	336
Total mass [g]	500
Energy of the driving spring [J]	2.2
Average/Peak power consumption [W]	0.28/0.7

The presented efforts are focused on two different activities. The first one is ESA-supported PECS project and includes optimization of mole penetrators and investigations of the mole penetration effectiveness in the lunar analogues [6], [10]. The second activity is connected with L-GIP project which involves designing an integrated system for deployment on planetary surfaces that consists of a seismometer, magnetometer and a heat flow probe. Numerical calculation of the heat flow [7], [8] and design and development of the Heat Flow Probe Hardware Component (HPHC) are the tasks performed by SRC PAS in L-GIP project [1], [9].
The work presented in this paper provides the results from the tests of the mole penetrator KRET in dry quartz sand and newly developed lunar regolith analogue AGK-2010 (created in cooperation between SRC PAS and AGH University of Science and Technology) in new test-bed system allowing for tests to be performed at the depth of up to 5 meters. The dynamics of the mole during one stroke are also presented.

MOLE PENETRATOR

The principle of operation of the mole bases on the interaction between three masses: the inserted cylindrical casing, the hammer, and the rest of the mass, acting as a support mass. Additionally, the driven spring should act on the hammer and the support, and the return spring should act on the support and the casing.

In a single work cycle (one stroke) of the mole KRET four phases can be distinguished (Fig. 2):
PHASE 1: Driven hammer compresses the driven spring.
PHASE 2: Released hammer accelerates and hits the casing. As a result of exchange of energy and momentum, the casing is inserted at Δx_1. The support moves in the opposite direction.

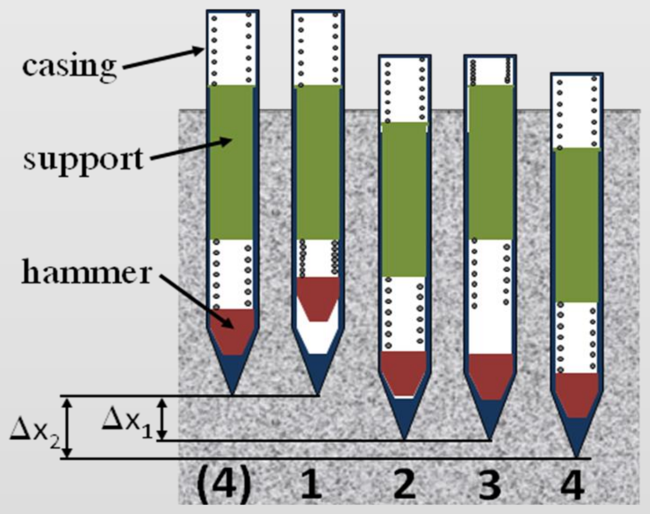


Fig. 1 Schematic principle of operation of the mole

PHASE 3: The support reaches the highest position compressing the return spring.
PHASE 4: The support accelerated by the return spring and gravity hits the casing and causes its additional move. Total progress of insertion is Δx_2.

Fig 2. The laboratory model of the mole penetrator: casing with the tip (bottom) and the hammer with the support (top)

Single-stroke dynamics

During Phase 2 and Phase 4 of the mole work cycle two high peak forces are applied to the casing. The first one appears when the hammer hits the mole casing and transfers the energy, theoretically with zero loss. The second stroke comes from support mass accelerated by gravity and return spring. In the Fig. 3 the position profile of the mole casing is presented.

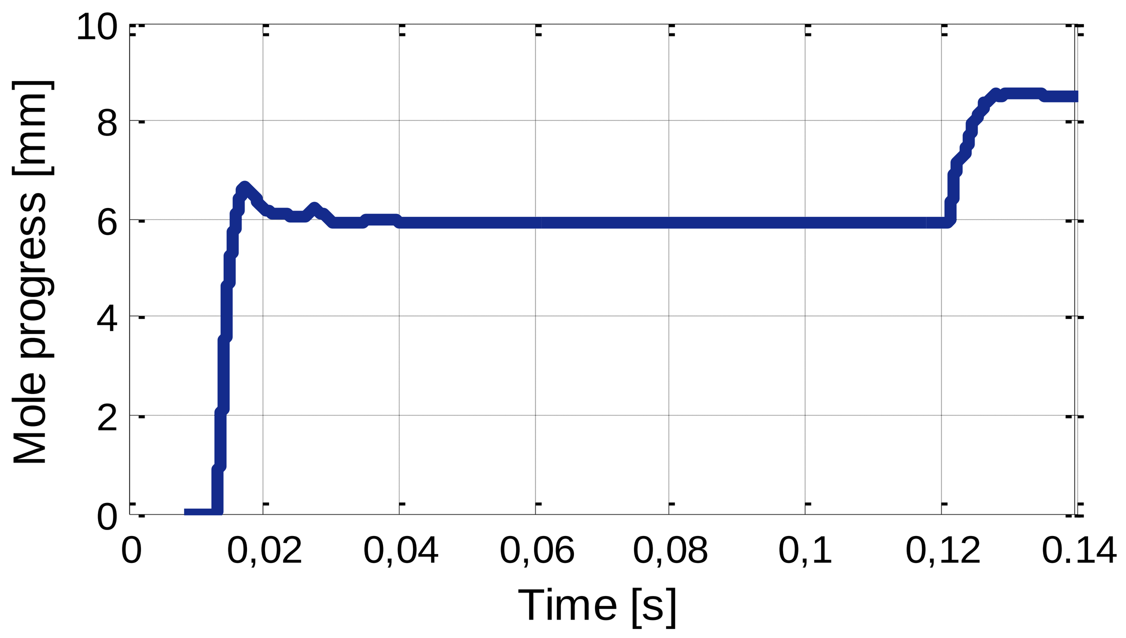


Fig. 3. Position profile of the mole casing

Results of tests in 5m test-bed system

The progress of the mole penetrator in granular medium depends on the mechanical properties of this medium. To ensure conditions comparable to the ones on the Moon, a new analogue of the Moon's regolith has been developed.
This analogue called AGK-2010 is based on the particle size distribution of CHENOBI lunar highlands physical regolith simulant and has the same mechanical properties (e.g. shear durability). Constructed at SRC PAS vertical 5-meter test-bed is presented in the Fig. 4.
Successful tests of the mole penetrator in quartz sand and lunar regolith analogue AGK-2010 were performed in summer and autumn 2010. The main results are presented in Fig. 5 where the progress of the mole in quartz sand and lunar regolith analogue with different compaction levels (ratio of material volume before compaction to material volume after compaction) is shown.

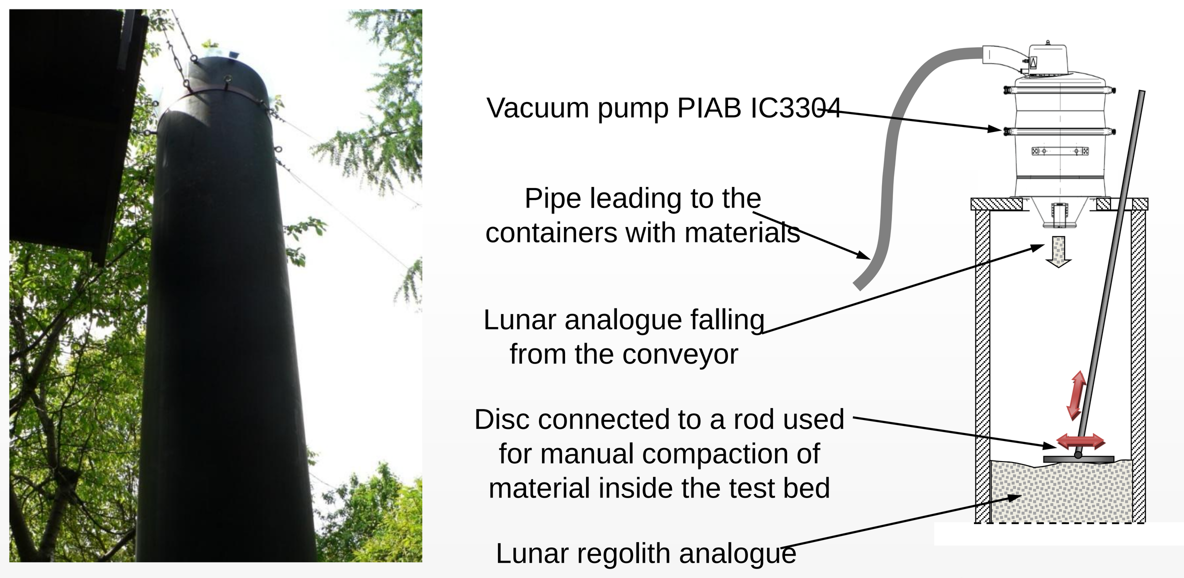
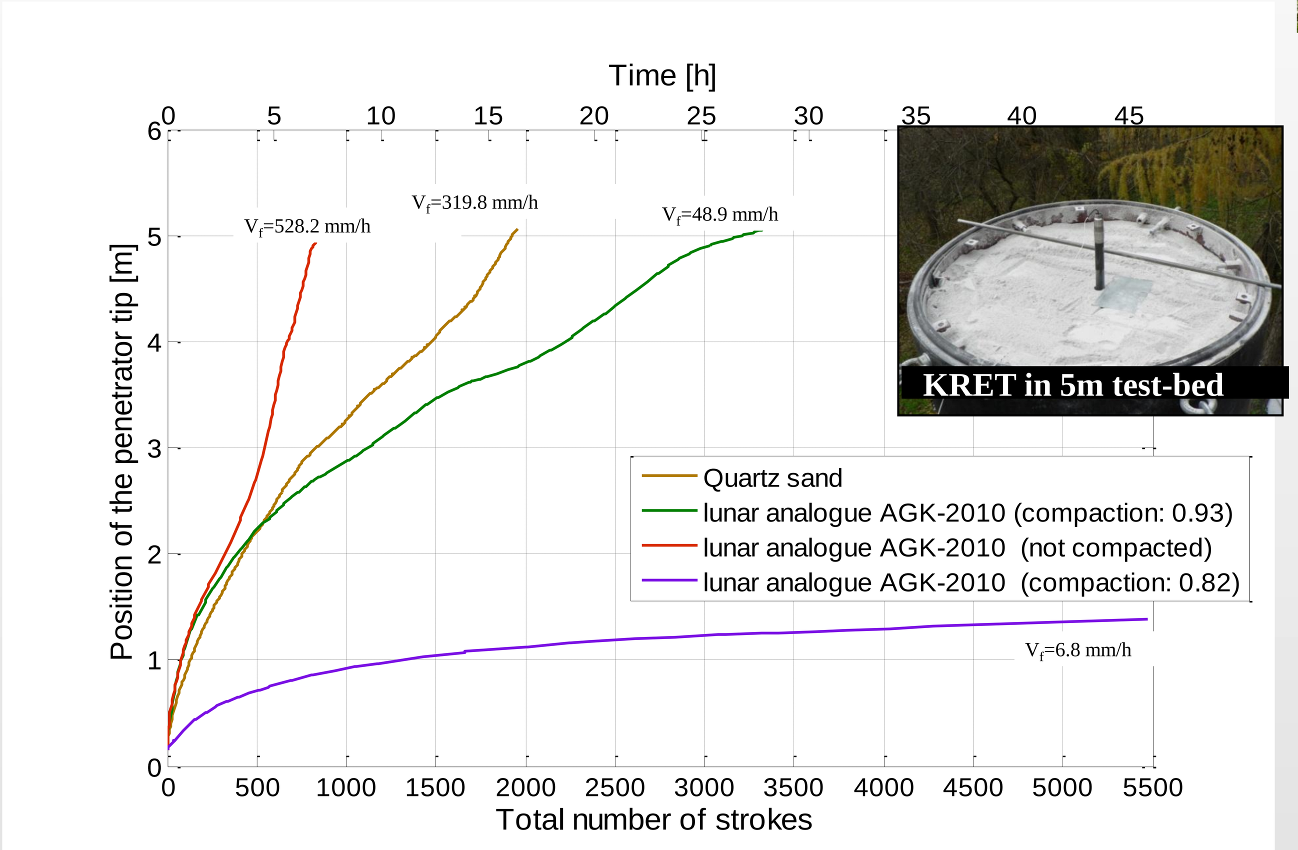


Fig. 4. The 5-m test-bed (top) and the mole KRET in the test-bed before and after commencing the test (bottom).



No	Material	Av. progress [mm/stroke]	Av. velocity [mm/h]	Final velocity [mm/h]
1	Quartz sand	2.59	310.4	319.8
2	AGK – 2010 (not compacted)	5.72	665.9	528.2
3	AGK – 2010 (0.93 compaction)	1.59	180.8	48.9
4	AGK – 2010 (0.82 compaction)	0.26	30.2	6.8

SUMMARY

The results obtained during the project allow pointing out the following conclusions:
➢ Mole progress depends highly on the compaction level of the lunar analogue.
➢ Mole progress decreases up to ~1.5m depth and then remains constant which means that the mechanical resistance of the cable is negligible.
➢ Stroke energy of the mole is an important parameter when working in highly compacted materials.
➢ Performed experiments confirm that the mole penetrator is able to work in subsurface layers of planetary bodies assuming their surface is made of regolith material.
➢ Tests of the second version of the mole are planned in a 2-meter test-bed. This test-bed will allow us to simulate different gravities for the mole penetrator.

Acknowledgments

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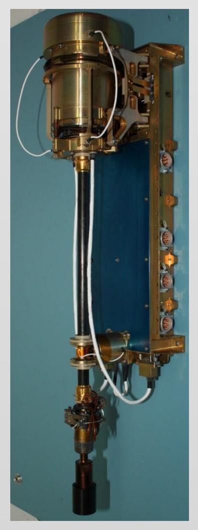
Other SRC space penetrometers dedicated for space bodies exploration

- MUPUS on the Phylae lander (Rossetta mission) to Chumurov Garasimienko comet - landing time - 2013 – main tasks: measurements of thermal and mechanical properties of the comet subsurface layers.
- CHOMIK (eng. hamster) on the Phobos Grunt mission – landing time – 2012 – main tasks: sampling of the Phobos regolith and measurements of the thermal and mechanical properties.

All penetrometers (photos included below) increase the knowledge of the subsurface layers in context of the future planetary bodies exploration (for example lunar base development).



REFERENCES

[1] Weinberg, J. D.. et al. (2008) *LPSC XXXIX.* [2] Gromov, V.V. et al. (1997) *7th European Space Mechanisms & Tribology Symposium*, ESTEC. [3] Grygorczuk, J. et al. (2007) *J. Tel. Inf. Techn.* 1/2007. [4] Spohn, T. et al. (2007) Space Sci. Rev, 128. [5] Grygorczuk, J. et al. (2008) *LPSC XXXIX*. [6] Grygorczuk J., et al. (2009) ESMATS Proceedings, ESA SP-670. [7] Banaszkiewicz, M et al. (2007) *Adv. Space Res. 40(2)* 226-237. [8] Seweryn, K.. et al. (2008) *LPSC XXXIX*. [9] Wawrzaszek, R. et al. (2009) *LPSC XL*. [10] Seweryn K., et al. (2009) *Penetrometry in the Solar System II*, Austrian Academy of Sciences Press.