**INSERTION OF A MOLE PENETRATOR – EXPERIMENTAL RESULTS.** J. Grygorczuk[1] K. Seweryn[1] R. Wawrzaszek[1] and M. Banaszkiewicz[1], [1]Space Research Centre Polish Academy of Sciences ul. Bartycka 18a 00-716 Warszawa, Poland (jurekgry@cbk.waw.pl, kseweryn@cbk.waw.pl).

**Introduction:** The work presented in this paper is focused on the dynamics of a low velocity penetrator that is driven into a granulated medium. Surface and subsurface material of planets (and its moons), comets and asteroids often consists of granulated matter with grain size in a range from several μm to several mm, like terrestrial sand. For example, on top of the Moon's crust there is a highly comminuted surface layer of regolith. It has been estimated that the regolith thickness varies from about 3–5 m in the maria, and by about 10–20 m in the highlands [1].

The mole penetrator can be considered as a transport device for different sensors designed for *in situ* investigations in subsurface environments [2], [8], [9]. The mole is driven by the hammering mechanism, which accumulates energy in the spring and allows the mole to move by forward directed internal shocks. In recent years, several mole penetrators have been designed and tested in the laboratory [3], [4]. Some of them were prepared for space missions, e,g. the one developed by DLR in Cologne for the Beagle 2 lander on ESA Mars Express mission [5], [6]. Another interesting device is the $HP^3$ instrument proposed by DLR Berlin for the ExoMars mission [7]. Here, we present a new mole developed in SRC, Warsaw.

**Mole penetrator design:** The mole consists of three main subassemblies: the outer tube, the hammer and the counter-mass. There are two springs: a driving spring (providing energy of 2J) between the hammer and the counter-mass and a return spring (several times weaker) between the counter-mass and the tube. All mechanisms that are implemented in the counter-mass are stacked in-line: a DC motor, a reduction gearbox, a ball screw and a special latch which is meshed with the hammer during the compression of the driving spring and released before the hammer stroke. The latch and the ball screw are used in order to be able to apply the high energy driving spring.

The outer tube of the mole, designed and developed in SCR PAS, is made of carbon fibre, while the penetrator conical tip (opening angle 45° to 30°) is made of titanium. The combination of both elements results in a good strength to weight ratio. The hammer is made of hardened stainless steel. Most of the parts of the counter-mass (excepts of mechanisms) are made of tungsten alloy. This is as much important as the high energy of the driving spring, because with this material the rebound energy is decreased and the insertion efficiency is improved. The choice of carbon fibre and tungsten results in close to optimal proportions among the outer tube, the hammer and the counter-mass: 1 / 1.25 / 10.

Fig. 1 The laboratory model of the mole penetrator: the outer tube with the tip (left), the hammer with the countermass (middle) and an artistic concept of the mole (right).

The mass of the 330 mm long and 20 mm wide mole is 450 grams. This first prototype will be further developed to improve its parameters. The next model will also be better conformed with the mission constrains.

**Experimental Testbed:** To obtain information about the mole position in the ground, a number of measurement methods, such as contact (measure wire connection) or remote (linear encoders, metal detector, echolocators, geophone and others) are considered. In this paper we describe a passive sound system based on 14 microphones. Ten of them are uniformly, vertically spaced along the container wall (Fig.2). The remaining four sensors are located in different places inside the medium sample. By simultaneous recording of acoustic signals (waveforms) generated by a stroke of the mole, it is possible to determine the position of the mole. In the considered experiment, each microphone has its own, separate amplifier and measurement channel. Digitalization and postprocessing of the signal is done by using a National Instrument system.

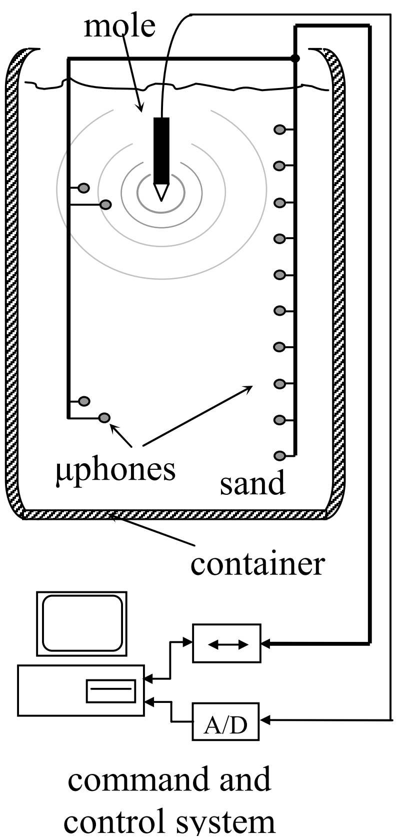


Fig. 2 Testbed system: container with dry quartz sand, passive measurements system with μphones, mole penetrator and the data acquisition system.

The accuracy of the passive sound method is, in this case we present, about 1.5cm. This is enough to obtain an average speed of penetrator insertion into the surrounding medium. Dynamic characteristics of device during one particular stroke, are obtained by employing a linear encoder system that is based on a magnetic tape. The magnetic tape system has its limitations: this kind of measurements can be done only in the case of a partial insertion of the mole in the medium (sand).

**Results:** The laboratory version of the mole penetrator was designed, developed and successfully tested in a testbed filled with dry quartz sand. Two types of dynamic characteristics were obtained during the mole insertion. The first one shows the overall mole insertion progress (crude scale), while the second one corresponds the time evolution of the mole velocity during a single stroke of the hammer (fine scale).

**Acknowledgement:** The authors are very grateful to B. Dąbrowski, P. Coste and L. Richter for numerous discussions about the subject. The paper was partially supported from the KBN project no N522 003 31/1166.

**References:** [1] Heiken, G. et al. (1991) (eds.), Lunar Sourcebook, a user's guide to the Moon, 736, Cambridge University Press, New York. [2] Banaszkiewicz, M et al. (2007) *Adv. Space Res. 40(2)* 226-237. [3] Gromov, V.V. et al. (1997) *7th European Space Mechanisms & Tribology Symposium*, ESTEC. [4] Lorenz, R.D. and Ball A. J. (2001) *Penetrometry in the Solar System*, Wien. [5] Coste, P. (1998) *Proceedings of ESA Workshop on Advanced Space Technologies for Robotics and Automation - ASTRA,* ESA/ESTEC. [6] Richter, L. et al. (2002) *Planetary and Space Science*, 50 903-913. [7] Knollenberg, J. et al.(2007) *EGU*. [8] Seweryn K. and Grygorczuk J. (2006) *Proceedings of the Workshop on Space Technologies*. [9] Dabrowski, B. and Banaszkiewicz, M. (2006) *Proceedings of ESA Workshop on Advanced Space Technologies for Robotics and Automation - ASTRA*, ESA/ESTEC. [10] Spohn, T. et al. (2007) Space Sci. Rev, 128.