USDC based rapid penetrator of packed soil

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ABSTRACT

Environment protection requires more testing and analysis tools. To detect buried chemical containers or other objects embedded in soil and avoid possible damages of them, a penetrator of packed soil operated using low pushing force was developed. The design was based on a novel driving mechanism of the ultrasonic/sonic driller/corer (USDC) device developed in the NDEAA lab at JPL [Bar-Cohen et al 2001, Bao et al 2003]. In the penetrator, a small free-flying mass is energized by a piezoelectric transducer and impacts a rod probe on its shoulder at frequencies of hundreds times per second. The impacts help the probe to penetrate the packed soil rapidly. A great reduction of the needed pushing force for penetration was achieved. The details of the design of the prototype penetrator and the results of performance tests are presented.

Keyword: ultrasonic/sonic, soil penetration, chemical detect, embedded container

1. INTRODUCTION

To detect chemical containers or other objects embedded in soil, penetrators of packed soil operated using low pushing force are needed. The penetrators need to be used to detect and conduct analysis of chemically hazardous areas at minimal disruption/penetration forces to prevent rupture of the container in which the chemicals are stored. The possibility results from the concern of severely corroded or eroded container walls and an accidental rapture of the wall may cause a spill that would pose great hazard. Using traditional technology, the force required to plugging a thin rod probe of 1/8 – 3/16 inch in diameter into packed soil to ~3 feet depth is 50 – 200 lbs dependent on the consolidation of the soils.

The prototype penetrator with low pushing force was designed based on ultrasonic/sonic driller/corer (USDC) technology that developed at JPL. The search for present or past life in the universe is one of the most important objectives of NASA's mission. Sampling in low gravity environment (as on Mars, comets, and asteroids) using conventional drilling and coring techniques is limited by the need for high axial force. Jointly with Cybersonics, Inc., a novel USDC mechanism was developed overcoming this and other limitations of conventional drilling and sampling techniques [Bar-Cohen et al, 2001, Bao et al 2003]. The USDC mechanism is based on an ultrasonic horn actuated by a piezoelectric stack, which impacts a free-mass resonating between the horn and a drill stem. The USDC involves mechanical frequency transformation via the free-mass allowing the drill bit to operate in a combination of the 20 kHz ultrasonic drive frequency and a 60-1000 Hz sonic hammering action. This novel drill is capable of high-speed drilling using low axial preload and low power, and it is highly tolerant to misalignment. The USDC was demonstrated to operate from such robotic platforms as the Sojourner rover and the FIDO robotic arm and it has been shown to drill rocks as hard as granite and basalt and soft as sandstone with pre-load of 2 – 20 N. In Figure 1, the USDC is shown being held from its power cord while drilling a sandstone rock -- this is possible because relatively low axial preload is required. This feature is a main merit for the application of the USDC technology to soil penetrator. In addition, considering the fact that the drill bit does not turn, it is possible to integrate sensors near the tip of the bit allowing examination of the chemical pollutions while penetrating the soil.

The details of the design of the prototype penetrator and the results of performance tests of the penetrator are presented.

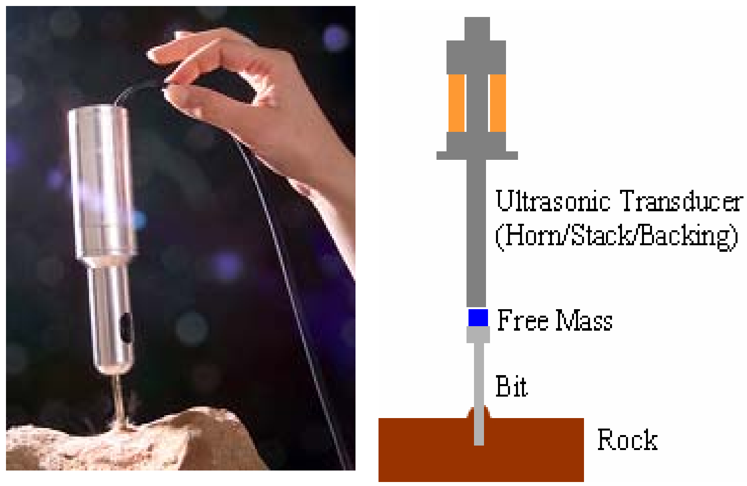

Fig. 1: A photographic view of the USDC showing its ability to core with minimum axial force (left), and a schematic diagram of its cross-section (right).

2. STRUCTURE OF THE PROTOTYPE PENETRATOR

The prototype soil penetrstor was designed and constructed based on the developed USDC. A schematic diagram of the structure of the prototype is presented in Fig. 2. The ultrasonic transducer consists of four PZT rings with a stainless steel block in back and a Titanium horn in front. All the components are held together by a high strength bolt, which provides pre-stress to the PZT elements. The transducer is xx inch long and 1 inch (25mm) in diameter. The probe is a 1/8 inch stainless steel rod with a shoulder at 1 m from the front end. A bullet-shape head with round tip is mounted at the front end on the rod. The free mass with a center hole is put between the horn and the shoulder. A center hole was made in the transducer and allows the rod goes through. A holder cylinder is mounted at the back end of the rod. There is a spring between the holder cylinder and the back of the transducer. The spring pushes the transducer toward to the free mass and the shoulder. The force is adjustable for best free mass bouncing condition in operation. In operation, the pushing force is applied on the holder.

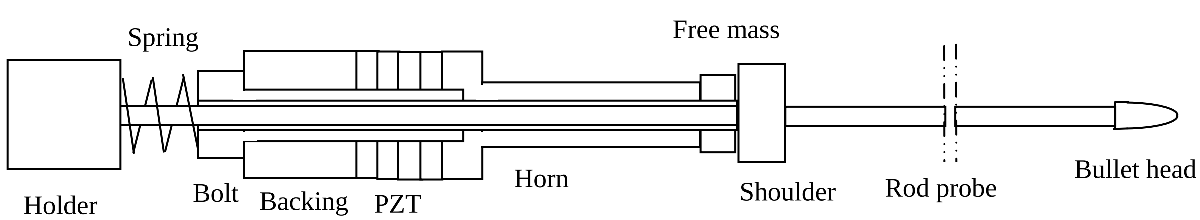

Fig. 2: Sketch of the structure of the prototype soil penetrator

3. PERFORMANCE TESTS

The test soil sample was washing sand. The sand was mixed with ~7% water in weight first for best compaction and, then, packed by a jack hammer with a plat head layer by layer in a tuber with 30-cm diameter. The total height of the soil sample was ~90 cm. The compaction of the sample was tested by a steel rod-probe of 3/16 inch diameter with a bullet shape head. The sample was more solid at the middle part. The force needed for ~30-cm penetration was 70 lb. The required pushing force was increased up to 140 lb when penetrating through the depth from 30 to 60 cm and gradually decreased in the range of 60 cm to the bottom.

The test setup is shown in Fig. 3. A tube was used to host the penetrator as a guider. A weight of 5 lb was put at the top of the penetrator to provide pushing force. The driving voltage, current and electric power to the penetrator were monitored by a Power meter and recorded by a connected computer as shown in Fig. 4-6. The depth of penetration was recorded manually (Fig. 7).

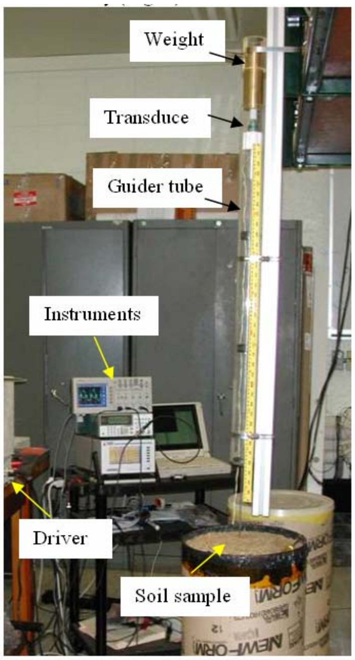

Fig. 3: Test setup

In the test, the penetrator with 5 lb pushing force successfully penetrated the sample and reached the bottom of the tube in 220 seconds (see Fig. 7). The driving voltage was 180 V (see Fig. 4), the averaged current was ~0.33 A (see Fig.5), and the averaged power was ~23 W (see Fig. 6). The penetration speed varied with time as shown in Fig. 8. Actually it basically correlated to the solid-ness of the packed soil. The speed varied with the depth is presented in Fig. 9. It was 1.2 cm/s at the beginning, reduced to 0.08 cm/s when passing the most solid part near a half of the whole depth and increased to 0.8 cm/s before reaching the bottom. The USDC mechanism can greatly increase the penetration capability of the penetrator without increase the pushing force.

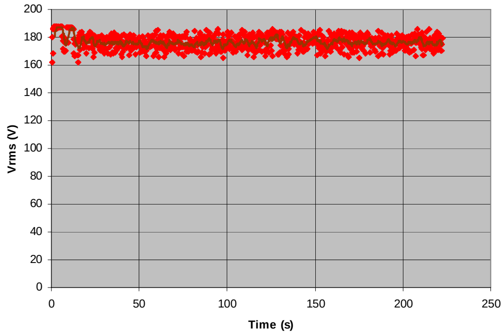

Fig. 4: Input voltage of the transducer, the dots represent data points and line is the average.

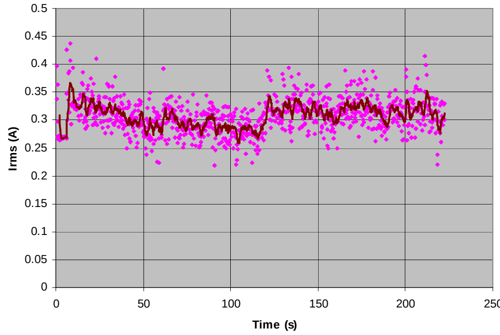

Fig. 5: Input current of the transducer, the dots are data points and line is the average.

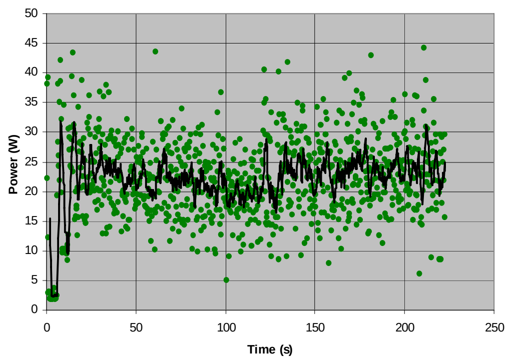

Fig. 6: Input power of the transducer, the dots are data points and line is the average.

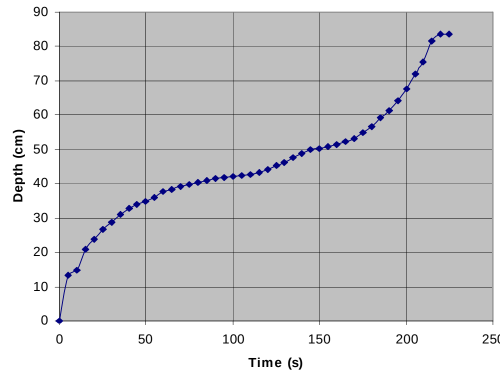

Fig. 7: Penetration depth vs. time

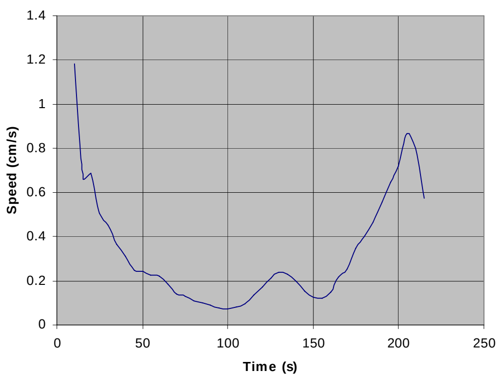

Fig. 8: Penetration speed vs. time

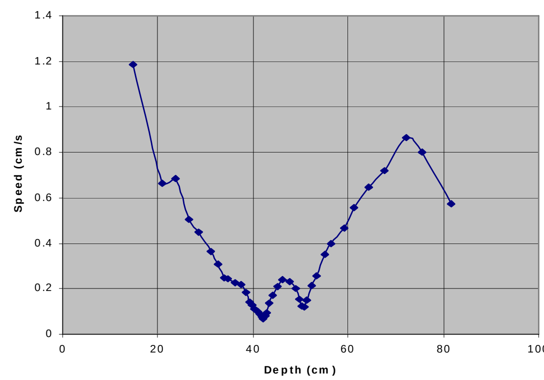

Fig. 9: Penetration speed vs. depth

The effects of the penetrator to various buried objects were verified. The tested objects include plastic bottle, clay tube, PVC pipe and brick. The test objects were buried in the packed soil. The probe of the penetrator was run toward to the objects and the power was kept on continuously for 12 seconds after the probe reached the objects. The conditions of the objects were checked after the test. Fig. 12 is the photograph of the tested plastic bottle. The penetrator only made a 0.3-mm deep notch on the surface. The tests of buried object are summarized in Table 1. No tested objects were damaged.

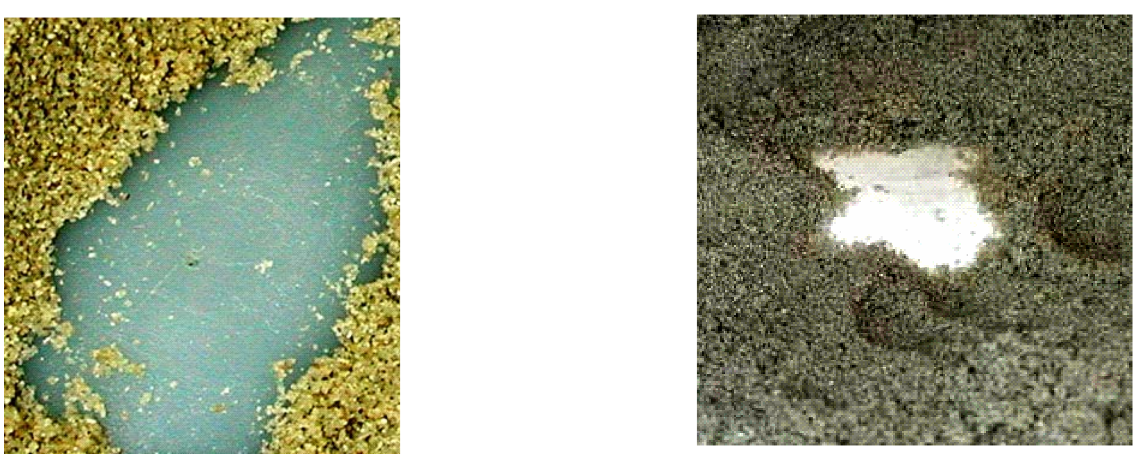

Fig. 10: Notches made by the penetrator, left – on a plastic bottle, right – on a PVC tube

Table 1 Summary of the tests on the buried objects

Buried object	Description	Effect of the 12-second operation of penetrator
Plastic bottle	Diameter = 90 mm, Wall thickness = 1.25 mm	Notch on surface, diameter ~1.5 mm, depth ~0.3 mm
PVC pipe	Diameter = 50 mm, Wall thickness = 4 mm	Notch on surface, diameter ~1.2 mm, depth ~0.4 mm
Clay tube	Diameter = 150 mm, Wall thickness = 6 mm	Notch on surface, diameter ~2.5 mm, depth ~1.5 mm
Brick		Notch on surface, diameter ~2 mm, depth ~1.4 mm.

4. SUMMARY

Based on the novel driving mechanism of the USDC devices that were developed for planetary sampling by NDEAA Lab at JPL, a prototype penetrator for packed soil was developed. The rod probe of the penetrator was driven by the impacts of a small free-flying mass that was energized by an ultrasonic transducer. The penetrator successfully reduced the required pushing force from more than hundred pounds to 5 pounds. The potential application is to detect buried hazardous chemical container or other objects in packed soil, or to send sensors in to the soil. The low pushing force reduces the possibility of damage of the containers. Preliminary tests show that the effects of the penetrator to the plastic containers and other objectors are minor.

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