Quarterly Report – Public Page

Date of Report: *October 6, 2006*

Contract Number: *DTPH56-06-T-000005*

Prepared for: *DOT/PHMSA and AwwaRF*

Project Title: *Differential Impedance Obstacle Detection Sensor (DIOD) – Phase 2*

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For quarterly period ending: *September 30, 2006*

Progress to date:

The Quarter 1 report described the functioning of the original DIOD model and a proposed modified design. The finite element analysis reported in that report utilized an electrostatic formulation mode and assumed that the drill head is suspended in air, which is equivalent to the drill head placed on a work bench in the laboratory. The dataset generated was intended to form the basis for validating the model during the experimental phase of the project. There was also some preliminary modeling performed to examine the feasibility of incorporating other technologies, such as Ultra-wide band (UWB.)

In Quarter 2, modeling was performed to compare the original and alternative DIOD designs when embedded in soil (a conductive dielectric medium.) The quasi-static electric current mode in COMSOL was used in all simulation series. The analysis demonstrated that by limiting the source to a location in the forefront of the drill head assembly the field lines are better focused towards the center of the object. Furthermore, the field lines are projected further ahead in the case of the modified design and follow shorter return paths.

The first two parametric studies assumed that the DIOD is encased in dry sandy soil with permittivity of 2.5 and conductivity of 0.002 S/m. The first study examined the responses of the sensors as the drill head advancing perpendicular to the orientation of the obstacle. The obstacle consisted of a 1 m long, 150 mm diameter cylinder with a permittivity of 10. The results of the simulation reveal that as the drill head approaches the obstacle, voltage potential readings in the sensors for the original and modified DIOD models are -3.28± 0.03 volts and -3.54± 0.08 volts. These values are significantly greater than those predicted by the static model (i.e., DIOD suspended in air) for the original and modified designs, respectively. As the distance between the obstacle and the sensors shortened from 1.0 m to 0.45 m, the sensors' voltage readings increased by approximately 0.06 V and 0.08 V for the original and modified DIOD designs, respectively. While this change is adequate to detect the presence of an obstacle in a perfectly homogeneous environment, it might or might not be adequate in a real-world heterogeneous environment. The only way to answer this question conclusively will be to conduct a carefully designed and executed experimental testing.

The second parametric study focused on the drill head approaching a target at an angle other than 90 degrees. Numerical simulations were undertaken for intersection angles ranging from 60 to 120 degrees. For both designs a small drop in the potential readings was noted for angles smaller than 80° (approx. 0.03 V), while for angle angles between 80° and 120° voltage readings remained nearly constant. Thus, it can be concluded that the detection ability of DIOD does not decline for angles other than 90 degrees. On the contrary, since the electrical field line density is greater alongside of the drill head, approaching a linear obstacle at relatively shallow angles (<45° or >135° from the horizontal) is likely to increase the detection sensitivity of the device.

The third parametric study examined the effect of the electrical characteristics of the soil, namely permittivity and conductivity, on the readings at the sensors. Using the quasi-static electrical current model a change in permittivity had a negligible effect on the voltage potential readings at the sensors. Furthermore, changing the conductivity value to from 0.002 S/m (dry sand) to 0.02 S/m (sandy soil with 6% moisture content) while keeping the permittivity constant (=20) also resulted in limited effect on the sensitivity of the sensors. Currently, a literature review is undertaken to compile a database of conductivity values for various soil types with a range of moisture contents. Analysis conducted using this data will be used to support experimental measurements during the next phase.

Encasing the DIOD designs in a soil medium resulted in a significant increase in the base voltage value recorded in the sensors. However, the sensitivity of the sensors to disturbances in the electric field increased in a more moderate fashion, primarily due to weak coupling between the field lines and the sensors. The design of the modified mechanical model was altered such that the sensor element was placed further backward from the drill bit in an attempt to intersect a greater percentage of the current field lines. However, this modification resulted in the field lines migrating further down the drill stem behind the sensor element (i.e., coupling to the sleeve).

Some additional UWB modeling was also performed in Quarter 2. It was shown that positioning the UWB pulse emitter and the receiver at the head of the HDD device greatly improves the underground detection capabilities of the device. As in the case shown by Nakauchi, Arai and Hayakawa (2000), it can be concluded that it is possible to build a small ground penetrating radar sensor based on UWB radiation able to fit into HDD devices by exploiting the properties of a small horn antenna described by Li et al. (2003). Realistic simulation of an HDD device in three-dimension, pulse propagation through the soil and scattering from different buried objects using FDTD, together with the experimental modeling, will make the design of a small robust UWB radar system for short-range high resolution underground detection possible. Such system can fit with already existing DIOD system with no interferences.

The amount of work to design and test complete system, however, is not trivial. It should be separated into designing the UWB radar electronics, designing of the antenna and receivers, simulating the system characteristics, building and testing a prototype. UWB technology is developing rapidly in last few years and it is important to be in the forefront of this development.

Research will now progress from the modeling task to the fabrication/testing task. GTI and La Tech will first perform tests of the current prototype to verify the results agree with those approximated by the 3D model. A small test cell will be created to take measurements of the loam soil properties with and without small obstacles to compare against those models generated to predict results when a similar soil medium is present. If the results are similar to one another, modifications will be made to the prototype to verify the results approximated by the alternate drive and sense configuration.