# TransTech Systems' Pavement Quality Indicator™ (PQI) Technical Application Brief

Density of hot mix asphalt is the most important construction variable in the durability of asphalt pavement surfaces. All current methods of measuring asphalt pavement density have major limitations. Destructive core samples and laboratory measurement are time consuming and costly. Useful information does not reach the paving crew in time to make any corrections to the paving process. The alternative, nuclear densitometers, currently the "gold standard" in the industry, are cumbersome to use, require strict licensing and usage procedures, take several minutes to get data, and have limitations in their accuracy. Further, the time required by nuclear devices to obtain useful density data limits their in-process, Quality Control (QC) effectiveness during pavement construction.

## Theory of Operation

The reason this device is innovative is that, through the use of its constant voltage, radio frequency, electrical impedance approach, in which a novel toroidal electrical sensing field is established in the material being tested, the PQI is able to make instantaneous, in-situ measurements of pavement density. The sensor consists of a unique set of flat plates that are interconnected to form the electrodes of a planar capacitor. Changes in the asphalt density change the dielectric constant of the medium between the capacitor plates. The resultant measured capacitance is increased in proportion to the change in dielectric constant. Dielectric constant is related to the measured capacitance by an equation similar in form to the standard equation for parallel plate capacitors

$$C = \frac{k\varepsilon_0 A}{d} \qquad \text{Eq. 1}$$

where C is the measured capacitance, A is the area of the plates, d is the plate separation, is the premittivity of free space, and k is the dielectric constant. For the PQI configuration, the A and d terms are replaced by spatial integrals. Many researchers have shown that the dielectric constant of a multi-constituent matrix, such as asphalt, is found to be proportional to the volume fractions and dielectric constants of the individual constituents according to an empirically derived dielectric mixing equation

$$k = \left(\nu_w \times k^{\alpha}{}_w + \nu_p \times k^{\alpha}{}_p + \left(1 - \sum \nu_n\right) \times k^{\alpha}{}_a\right)^{1/\alpha} \qquad \text{Eq 2.}$$

where the $k_n$ are dielectric constants of the constituents and the are the volume fractions of the constituents. The term is an empirically determined constant that is different for each matrix and which accounts for dielectric polarization effects and constituent interaction effects. Hot mix asphalt (HMA) of the type used for paving can be characterized as a four-component mixture: asphalt cement (k=2.8), stone aggregate (k=3-5), water (k=80), and air (k=1). During compaction, the volume fraction of the air is reduced. Therefore, since the dielectric constant of air is less than that of the other components, the dielectric constant of the composite mixture increases with compaction. Thus the measured dielectric constant is proportional to the level of compaction. Another innovation is the use of an electronically configurable system of sensor plates permitting control of the depth of measurement. An embedded computer allows the PQI to perform sophisticated calibration and correction functions and enables the device to store a number of readings for later retrieval and analysis.

The importance of this innovation is that relative density measurements can now be taken instantly, allowing for necessary changes to the rolling pattern to be made immediately, as well as making it possible to take many more readings per hour on the job site, both of which help ensure the best possible pavement quality. The device is light weight, easy to use and requires no special licensing. Thus, almost any member of the paving crew can operate it successfully. Improvements in the latest PQI Model 301, including its ability to compensate for surface water, together with the recent completion of a successful FHWA Five State Pooled Fund Study, which concluded that the use of the PQI for providing QC during paving is a perfectly acceptable method and provides results at least as good as the nuclear devices in widespread use today, have positioned the PQI as the ideal rapid measurement, non-destructive device for determining asphalt pavement density on the market today.

Currently, the PQI is a commercial product with over 400 units sold. It has been accepted internationally as well as domestically, and is now being used in more than 10 countries worldwide. It is fully expected that with its second patent in hand, the improved compensation for surface water, the success of the FHWA Pooled Fund Study and the anticipated AASHTO provisional spec, due out in August 2003, the PQI will steadily increase its market share by allowing paving contractors, state and local DOT/DPWs and the research community to take advantage of its rapid, accurate and repeatable pavement density measurements for QC as well as for vital research on road construction "hot topics" such as segregation, texture, permeability, sensor fusion, characterization of Superpave mats, density profiling, pre-construction mat profiling and density-on-the-run.

## Historical Development of the Technology

Research on determining material properties by dielectric property measurements dates back to the early 70's with Bell's work in capacitance measurements. Since then, numerous researchers, including Arulanandan, Topp, Roth, Hipp, et al, have extended this work and the research has resulted in the refinement of both hardware and in empirical dielectric mixing models for material characterization. Almost exclusively, however, this work has concentrated on measurement of moisture content and has focused on time domain techniques such as Time Domain Reflectometry (TDR). Several of these approaches have also been patented, but again, most of the patent art relates to moisture measurement in a wide variety of materials. TransTech has been issued two patents (5,900,736 and 6,414,497) applying the innovations described to the specific problem of measurement of the density of construction pavement.

TransTech Systems, Inc. began the initial phase of work on the PQI in 1995 at its original Latham, NY facility, under the New York State Energy Research and

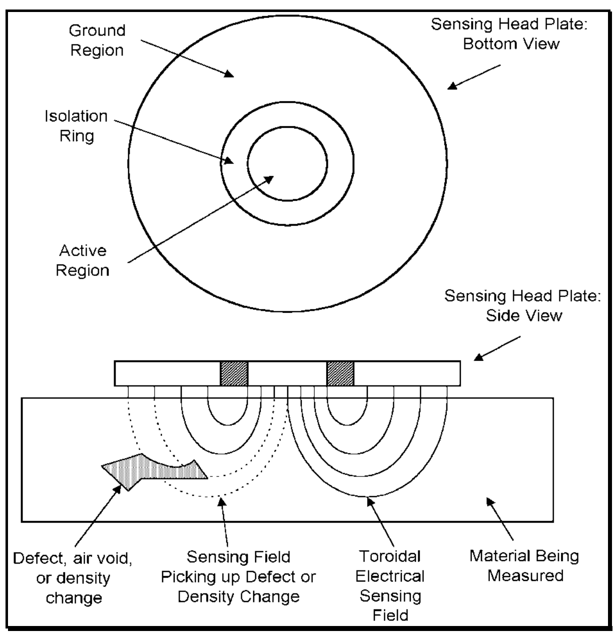
Development Authority Agreement 4354-ERTER-TR96. Throughout the five phases of the program, encompassing approximately six years, TransTech achieved outstanding results and has benefited from, in addition to its own internal funding, support from the FHWA and AASHTO, delivered through the NCHRP under the IDEA Program administered by the TRB, under the auspices of the National Academy of Sciences. In addition, the USACE, through WES, was a key supporter and has provided funding as well as critical technical guidance. Substantial technical support has also been provided by Rensselaer Polytechnic Institute faculty in areas including statistics, software development, materials studies and mathematical algorithms.

## Future Directions

Currently, TransTech is actively working to extend its electrical impedance technology to the measurement of compacted soil density. Other development directions include a non-contact version of the device and an instrument that can directly measure the standard 6-inch cores used for pavement QA/QC.

Pavement Quality Indicator™

Operational Theory Schematic





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