Development of a Noncontact Pavement Smoothness Monitor for Use During Construction

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ABSTRACT

A pavement smoothness monitor has been developed for use in road construction to allow pavement smoothness defects to be corrected while the pavement is uncured and to allow for better control of subsequent paving operations. The device operates within the paving train and measures the smoothness using an array of noncontact sensors. The operator is provided with profile traces, defect information, and a profile index number for use in assessing needed corrective action. A description of the device is given along with its specifications and a discussion of measurement method, sensor characteristics, and profile computer design.

The final measure of the quality of a road construction project as viewed by the driving public is the smoothness of the pavement surface. Many jurisdictions currently require contractors to meet specific smoothness requirements for final acceptance of the job. In many cases payment penalties are imposed on the contractor for smoothness levels that fall below certain thresholds. If work is considered below acceptable limits, the contractor is required to either grind or remove and replace sections of portland cement concrete (PCC) pavement. Asphalt pavement contractors may have similar requirements.

At present, surface smoothness is measured many hours after the placing of PCC pavement because the measurement devices must be able to ride on the pavement. At that time, repair of mildly substandard work is not feasible and to repair unacceptable work grinding must be used. Grinding is a costly method for improving pavement smoothness. A less costly method, which can be used not only to eliminate unacceptable pavement smoothness conditions but to improve the overall smoothness as well, is to refinish plastic concrete that is out of tolerance or substandard. The success of this approach depends on the contractor's ability to measure the profile of newly placed plastic concrete. At that time, modifications to the surface can be more easily accomplished. In addition to alerting the paving crew to a substandard product, a noncontact pavement smoothness monitor in the paving string can provide valuable feedback to the paving machine operator, so that adjustments to the paving operation can be made to ensure a smoother surface further along on the project. Typical adjustments would include better control of the concrete mix and ensure a more uniform delivery of concrete to the paving train.

The development of a smoothness measurement device that is designed to operate in a paving train and that provides the information necessary to improve the smoothness of pavement is discussed. In order not to affect the surface of the newly placed pavement the device uses noncontact sensors to measure the surface smoothness.

So far, only preliminary field testing has been conducted. A complete field-testing program is scheduled for the spring of 1984. The primary purpose of this testing program will be to evaluate the device under actual highway paving conditions.

GENERAL DESCRIPTION

The pavement smoothness monitor (PSM) design concept is shown in Figure 1. The device can be mounted on a four-wheel moving bridge such as a tube finisher chassis. Alternatively, the PSM can be attached directly to a paving machine.

In the moving-bridge configuration, four sensor beams are retained beneath the bridge. Positioning of the sensors with respect to road surface is noncritical, but for best results a measurement range of from 4 to 12 in. should be observed. Sensor position can be adjusted with respect to the pavement by raising and lowering the bridge. The vertical position of the beams with respect to the bridge can also be adjusted to compensate for road crowning. When attached to the paving machine, the beams are attached to brackets cantilevered off the rear of the float pan.

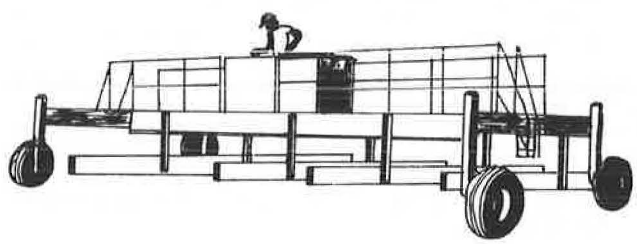


FIGURE 1 Four-beam pavement smoothness monitor mounted on texture/tube finisher chassis.

For detecting the pavement surface profile, 10-ft-long sensor beams, each containing five noncontacting distance measurement sensors, are passed over the road surface along a longitudinal path. This beam is shown in Figure 2. These sensors take simultaneous readings at a regular distance-based sampling rate. These data are fed into a microcomputer system that calculates surface profile for graphic representation. Four beams allow measurements to be taken along four separate paths on the pavement. The measurement system does not require the use of an external height reference such as a string line or laser beam because the multiple sensor array automatically compensates for vertical movement of the beam. Thus paver or bridge movement will not affect the measurement.

It is important that forward movement of each sensor array along the pavement be known at all times during the measurement survey for the computational reconstruction of the surface profile. Incremental distance is measured by a digital encoder on the drive system or attached to a fifth wheel.

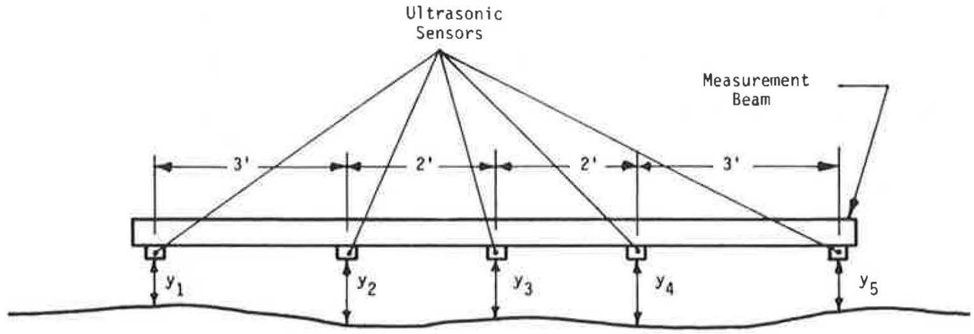


FIGURE 2 PSM measurement beam description.

HOW PSM IS USED TO IMPROVE SMOOTHNESS

The PSM provides the operator with several pieces of information that can be used to correct pavement deficiencies. First, the profile trace clearly displays all defects and provides their location so that defects can be hand repaired. A bridge-mounted PSM can be used to remeasure hand-repaired pavement to ensure that corrective actions have been adequate. Second, periodic waves in the pavement can be seen and their length easily assessed. These periodic waves can be the result of automatic leveling control inaccuracies, defects in the paving machine, nonuniform placement of concrete ahead of the paver, and so forth. Examination of the length of these waves will make the cause of the problem obvious in many cases.

The PSM allows the results of adjustment in the paving operation to be seen immediately. The operator can attempt various possible cures to a problem and observe the results in a short time. He thereby has set up a feedback loop between operational changes and their results.

The PSM also computes a profile index that can provide an indication of the overall quality of the job. If the profile index indicates poor quality, the contractor may want to take a hard look at his paving operations and take corrective action before additional paving of similar quality is placed.

Finally, the PSM may eventually be used to eliminate some of the current hand-finishing work if it indicates that the surface profile is good without further finishing.

METHOD OF MEASUREMENT

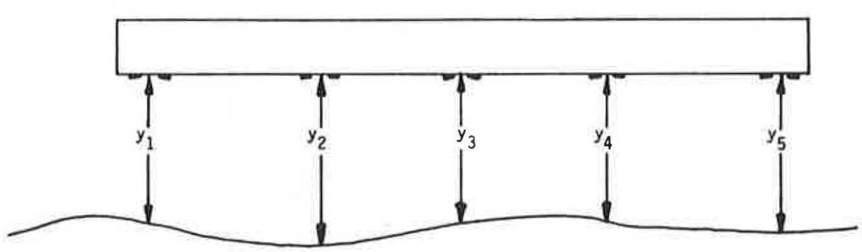
When a straightedge is placed on a pavement surface, it rests on the two highest points along its length. When the straightedge is viewed from the side, relative low points on the surface can be seen. The deviation at any point along the length of the straightedge is an offset from the chord formed by the two ends of the straightedge. At the center the offset is referred to as a midchord offset (MCO). The term chord offset derives from a basic straightedge technique of surface profiling that is currently performed during pavement construction using the straightedge or string line. If the straightedge is lifted off the pavement and noncontact sensors are placed along it, the MCO can be calculated without pavement contact.

Let us imagine a straightedge (beam) with five proximity sensors attached to it in a manner similar to that shown in Figure 3. The beam moves longitudinally above the road surface. If only three sensors are used, the measurements that are taken consist of the three sensor gaps y_1, y_3, and y_5 from which an MCO is computed as

$$MCO = y_3 - [(y_1 + y_5)/2]$$

It can be seen that the value of MCO does not vary as the beam is raised, lowered, or tilted. This is important because it is the basis on which this system eliminates the need for a fixed external reference system, thus allowing the wheels and bridge to move freely. Sensors 2, 3, and 4 are also used to calculate an MCO for a shorter chord.

The key aspect of this technique is that measurements are calculated on the basis of the sensor outputs and, through appropriate processing, a representation of the roadway profile is produced. From this curve, deviations in the road profile can be easily determined. A single three-sensor beam exhibits losses in frequency content whenever a deviation is encountered the length of which is evenly divisible into the beam length. To solve this prob-



$$MCO_1 = y_3 - \left(\frac{y_1 + y_5}{2}\right)$$

$$MCO_2 = y_3 - \left(\frac{y_2 + y_4}{2}\right)$$

FIGURE 3 Computation of midchord offsets using five-sensor beam.

lem, a five-sensor beam that measures two MCOs of different lengths and combines them to eliminate data losses is used. The device exhibits complete frequency response within its range (6 in. to 20 ft). The beam length and sensor spacing length are variables that can be altered to achieve better correlations with existing instruments such as the 25-ft profilograph if this is a requirement of a particular application. For most purposes, however, the 10-ft beam provides the required data for construction control.

SENSOR DESCRIPTION

Each profile measurement beam uses five pairs of acoustic (ultrasonic) distance measurement sensors to measure the distance from the beam to the pavement surface. Each pair consists of a transmitter and receiver mounted 1 1/8 in. apart and aimed slightly toward each other at a 6-degree included angle. The sensors are mounted at a nominal height of 8 in. above the pavement. The sensors operate at a frequency of 215 KHz to provide high resolution and to avoid interference from other noise sources. The sensors measure distance by measuring the time that it takes for a pulse to traverse the distance from the transmitter to the pavement and return to the receiver. This time measurement is corrected for temperature using a reference sensor that measures a fixed distance at all times. The system can discriminate to 1/10 of a cycle, which at 215 KHz gives the sensor a resolution of 0.007 in. When measuring profile, each sensor on a measurement beam and the reference sensor take simultaneous readings that are fed into the profile computer. These measurements are taken every 2 in. along a longitudinal pavement surface path.

PROFILE COMPUTER DESIGN

A box diagram of the profile computer system is shown in Figure 4. This system is distance driven to collect profile measurement data at fixed distances (2 in.) along its forward movement path. To produce a distance trigger, a tachometer is integrally coupled to a follower wheel. The 2-in. distance trigger is the signal that initiates the entire data collection, processing, and representation cycle.

The distance sensing array is made up of 21 ultrasonic transmitter and receiver pairs. These sensors are arranged in four beams of five sensors each. The extra sensor is used as a reference and is located in a fixed-distance arrangement. Each sensor has associated with it a separate signal-conditioning card; the output pulse width of the signal-conditioning card is equal to the time it takes a sound wave to leave the transmitter, reflect from the road surface, and return to the receiver.

The distance-triggering circuit is also used to control the speed of a printer so that output will be displayed as a function of distance.

The output of the transducer-conditioning card is used as a gate to a counter with a fixed clock. This produces a count that is proportional to distance. Because data-collection requirements are slow, the same six counters are used to collect data for all 21 sensors. Five counters are used to collect data from one beam. The sixth counter is always used as the reference. The four beams are successively sampled.

Data are collected from the ultrasonic transducers, temperature corrected, and scaled. These processed data are then used to form two midchord offsets. Scaling and addition of the two midchord offsets form the profile that is outputted to a recorder through a digital-to-analog converter. Representation of the data is graphic and distance based.

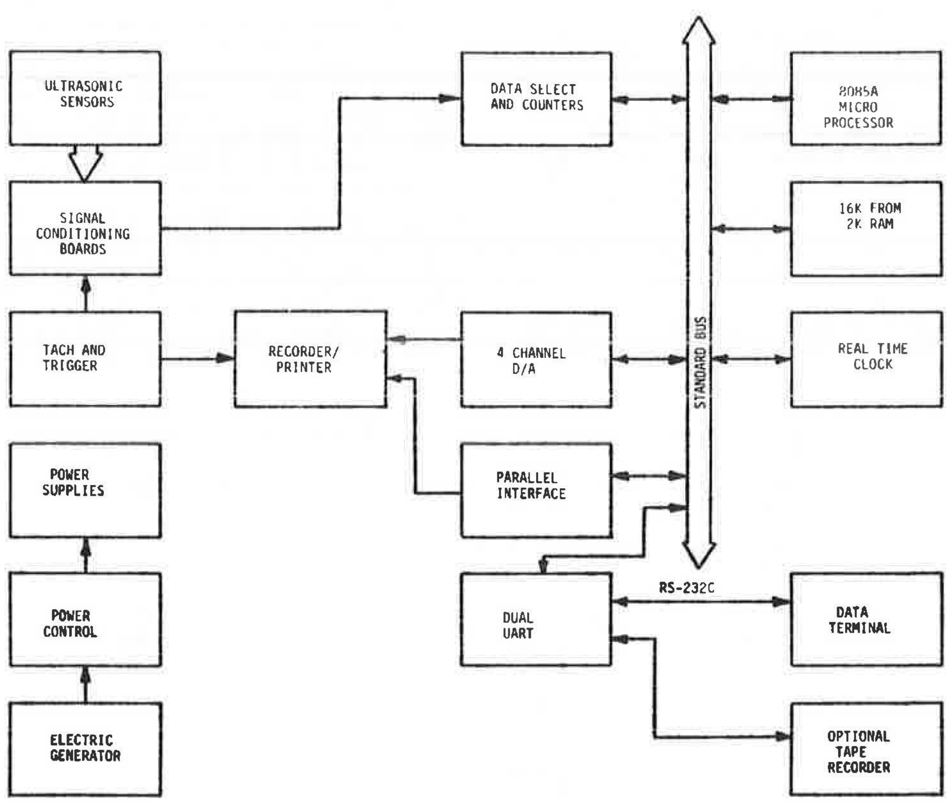


FIGURE 4 PSM computer system block diagram.

An industrialized RS232 terminal and printer (built into the recorder) complete the system. The terminal controls user input and is used for outputting system messages. The printer is used for displaying defect information, profile index, and printing permanent messages such as location, date, and the results of certain computations.

SPECIFICATIONS

The following specifications define the design limits of the device.

Environmental Specifications

The following specifications detail the environmental conditions under which the device will operate correctly:

Temperature Range

The PSM can operate and be capable of accurate and stable measurements over an ambient temperature range of 32°F to 113°F. Automatic compensation for temperature changes is provided.

Operating Humidity Range

The PSM will operate in a stable and accurate manner over all ranges of relative humidity.

Environmental Protection

The device will be used in a remote construction site and therefore was designed to withstand the rigors of such an environment, including (a) dirt, dust, mud, concrete, and water being thrown, blown, or sprayed on the device; (b) rain, snow, fog, or other form of precipitation; and (c) rough handling during transportation, storage, or use.

Measurement Specifications

These specifications describe the measurement capabilities of the system:

Resolution

The PSM is capable of resolving a difference in pavement height of approximately 0.04 in.

Accuracy

The device is capable of reproducing a measurement with an accuracy of ±5 percent of the pavement amplitude range on untined concrete.

Amplitude Range

The device is able to measure and reproduce profile height variations over a range of ±4 in.

Wavelength Range

Undulations in the road surface of wavelengths in the range of approximately 6 in. to 20 ft are measured and reproduced by the PSM.

Out-of-Specification Deviations

When the height variation of the pavement compared to the average pavement height over a distance of 10 ft (correcting for grade) exceeds some input value such as 0.30 in., the pavement will be considered out-of-specification and the PSM will so indicate.

Width of Roadway

The PSM is capable of measuring either one or two 12-ft-wide lanes of road on one pass.

Measurement Paths

The device is capable of simultaneous measurement along four longitudinal paths. Two paths will be measured for a single lane and two additional paths for the second lane. These paths are adjustable across the width of the lane.

Measurement Speed

The PSM is designed to measure pavement profile at speeds from 0 to 100 ft/min.

System Output Specifications

The PSM produces an output that can be used by a pavement inspector in refinishing the surface or in adjusting the paving equipment to produce a smoother pavement. The device produces both hard-copy strip-chart traces and a digital display.

Strip Chart Output

A hard-copy reproduction is made of the longitudinal surface profile at each of the sensor paths. These traces show profile height versus distance on parallel plots using a strip-chart recorder. The recorder produces marks at preset distances along the road. At the beginning of each page of output, the location and other pertinent information are imprinted on the chart.

Defect Display

A system is incorporated to indicate when the road pavement surface is out of specification. The variation in height of the pavement over a 10-ft distance will be monitored against an average pavement height. A defect situation will exist if this height variation is greater than some preset threshold (e.g., 0.30 in.).

Profile Index

The PSM automatically calculates a pavement profile index for each one-tenth-mile segment of pavement. The index calculates inches per mile of defect by adding up deviations in pavement amplitude that exceed a ±0.1-in. blanking band. In the future other indices such as the mean squares approach may be added.

Sensor Specifications

Sensors for use on the device do not make physical contact with the pavement surface. These sensors are capable of measuring uncured concrete, cured concrete, or asphalt.

The sensors can operate in a construction environment with little or no maintenance under the environmental conditions previously specified. The sensors measure the average height of a footprint about 2 in. in diameter. The sensors are not adversely affected by tining because they measure the peaks of the tined surface and disregard the valleys.

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A New Process and Apparatus for Making Asphalt Concrete

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ABSTRACT

The new Energy Efficient Mixer (EEM) makes possible a pollution-free and energy-efficient process. The EEM can heat and mix materials to a final temperature ranging from 60°C to more than 204°C (140°F to 400°F). There are three main components associated with the complete plant: a gas- or oil-fired thermal liquid heater (heater), a sealed and indirectly heated mixing chamber (processor), and the condensing coil-heat recovery bins (heat recovery). Compared with current processes for making asphalt concrete, the pollution-free EEM uses 20 to 30 percent less fuel per ton of product. This fuel economy is based on production of 140°C (280°F) mixture while removing 5 percent moisture. When the moisture content of the raw material exceeds 5 percent, the EEM process becomes even more efficient compared with existing processes. EEM thermal efficiency is made possible by effective recovery of the heat of vaporization contained in the removed moisture. In addition to cleanly and efficiently producing all types of asphalt concrete, EEM can produce new mixtures with a predetermined optimum moisture content. This optimized asphalt concrete mixture is produced by controlling the mixture temperature and the vapor pressure within the sealed mixing chamber. Furthermore, oxidation of the mixture is minimized because the heating and mixing take place within a sealed and pressurized chamber.

Current equipment for making asphalt concrete uses mostly direct-fired processes. In a batch process, the aggregates are directly heated and then mixed with the asphalt cement in a pugmill mixer. In a continuous process, generally known as a drum mix process, the mixture of aggregate and asphalt cement is directly heated. Current systems, particularly drum mix processes, give off and vent to the atmosphere significant amounts of hydrocarbons (blue smoke) and particulate matter. These systems also emit significant amounts of noise, and process problems are exacerbated by attempts to recycle asphalt concrete.

There have been attempts to control emissions from current processes by adding fabric filters and wet scrubbers. However, nonparticulate emissions are not effectively controlled by these devices. Problems such as mixture deficiencies due to collected microfine particulates (baghouse fines); corroded ducts, fans, and scrubbers (fuel); and baghouse fires or explosions (hydrocarbons) have resulted from these control efforts.

Current processes suffer from inefficient fuel use because they exhaust the removed water vapor to the atmosphere. This generally represents between 30 and 50 percent of the thermal energy consumed. With current systems, minimal recovery of the exhausted thermal energy would require large amounts of surface area. This is because of the presence of air (60 to 90 percent by volume) that is used as a medium to remove the water vapor.

For reference and to serve as a baseline of data, the following heat balance is for a typical 200-ton-per-hour (TPH) direct-fired asphalt concrete drum mix plant. The conditions are 140°C (280°F) mixture while removing 5 percent moisture.