Frensor: A New Smart Pavement Sensor

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A new solid-state pavement sensor, called Frensor, designed to measure the freezing point of moisture on bridge decks, roads, and runways is described. To optimize the use of deicing chemicals, the most important question is, Are there enough chemicals on the pavement to prevent ice formation? In other words, Is the freezing-point temperature of the water on the pavement surface well below the pavement temperature to be expected, or will it freeze unless more chemicals are applied? Using the Peltier principle and controlled by a microprocessor, the Frensor actively changes the temperature of the moisture deposited on its surface and provides an output of the pavement temperature and conditions. The conditions reported include dry, wet, wet but not frozen, dew, frost, and amount of chemicals on the surface. The freezing point is measured to an accuracy of ±0.5°C. The discontinuity plateau that represents the actual freezing point is linear with the amount of salt or chemical present on the pavement, over a calibrated range of −27 to 0°C. Thus, the Frensor provides a direct measurement of the freezing-point temperature of the material on the pavement, with which chemical application decisions can be made.

Significant effort has been spent trying to optimize the spreading of deicing chemicals on the road. Dedicated weather information systems exist today for the roads in several countries. One of the most important functions of these systems is to supply information to the people who decide when and where to spread deicing chemicals.

As is well known, the timing and dosage of the chemical is critical. It may be straightforward to make the decisions when there is no chemical left on the roads from earlier actions, but it is a much more difficult situation when chemicals have been spread earlier and precipitation and heavy traffic continue. The question is then, Is there enough chemical left on the road or not? or more precisely, Is the freezing point of the moisture on the surface well below the future temperature forecast for the road, which will then result in the liquid's freezing unless more chemicals are spread?

Several sensors on the market are designed to provide information about the road's surface; few, if any, actually measure the freezing point of the liquid on the surface. The Frensor described in this paper does measure the freezing point.

THEORY

A crystalline structure develops in a substance when it freezes. At the same time, the latent heat of freezing is released. Figure 1 shows a temperature-versus-time plot for water that is cooled below the freezing point. The temperature is essentially constant during the period of ice formation, after which it continues to fall. The inflection point in the curve at the freezing point of the water is caused by the release of latent heat of the water. The plot also indicates that the water is supercooled before freezing takes place. This happens if the water is quiescent and if few freezing nuclei are present.

A solution of salt in water has a freezing point lower than pure water. The freezing point is lowered by approximately 0.7°C per percent of sodium chloride in the solution. Figure 2 shows a temperature plot for a 5 percent salt solution; the freezing point is lowered to approximately −3.5°C. The existence and location of the inflection point in the temperature-versus-time plot is used to determine the status of the road surface.

SENSOR DESIGN

The design and installation of the Frensor is shown in Figure 3. There is a shallow cup in the upper side of the Frensor. Inside the Frensor is a Peltier element that is used to cyclically cool or warm the material in the cup, and the temperature of the moisture in the cup is measured as the Peltier element cycles. The temperature-versus-time data are measured by this sensor, and a microprocessor connected to the Frensor is programmed to use the measurements to determine the inflection point in the time-versus-temperature plot.

The Frensor is designed to ensure reliable and safe operation. The tires of passing cars and trucks press into the cup at the top of the Frensor, flushing the liquid material periodically. This forces new liquid into the cup so that the Frensor measures the solution on the road's surface as it changes. The cup is mounted in a tube that is pressed downward as the road and Frensor surface are worn down. The surface of the Frensor can be worn down more than 20 mm without performance being affected. Test results indicate that the lifetime of the Frensor will be more than 4 years, even on roads on which studded tires are used for 6 months of the year.

The power dissipated by the Frensor is less than 100 mW, and the Frensor is cast in an epoxy compound with thermodynamic properties matched to normal pavement. This means that the effect of the Frensor on the measurement of the freezing point of the material on the road's surface is negligible.

MEASURING ACCURACY

Figure 4 shows the arrangement of a Frensor and a reference platinum temperature sensor for a test of the Frensor's accuracy. The platinum sensor is glued to the bottom of the measuring cup. The Frensor is then activated so that the bottom of the cup is cooled, and the temperature of the cup

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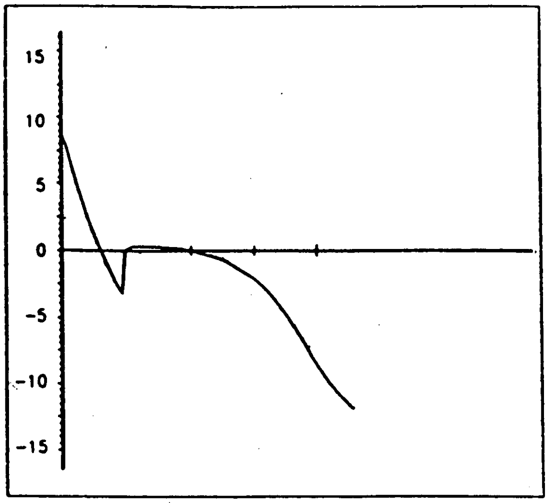

FIGURE 1 Time-versus-temperature plot for water; temperature is in degrees Celsius, and time marks are 5 sec apart.

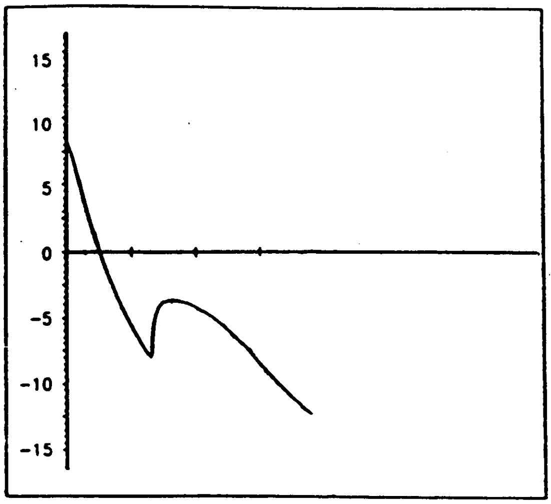

FIGURE 2 Time-versus-temperature plot for 5 percent salt solution; temperature is in degrees Celsius, and time marks are 5 sec apart.

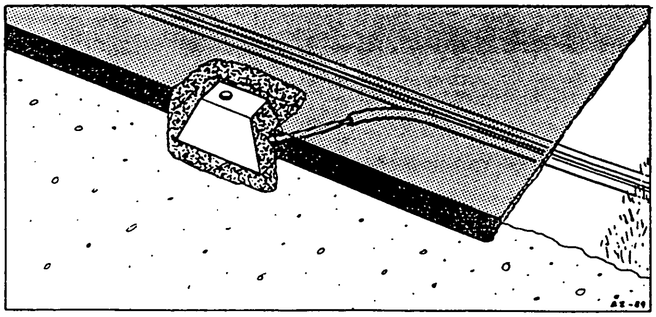

FIGURE 3 Design and installation of Frensor.

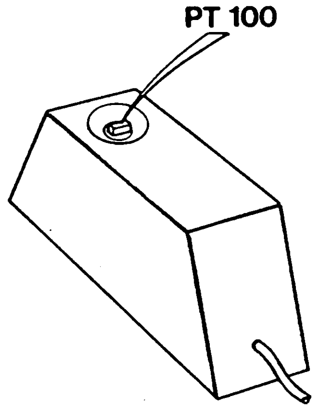

FIGURE 4 Arrangement of Frensor and reference PT 100 temperature probe for test of Frensor accuracy.

bottom is measured with both the Frensor and the platinum sensor.

Figure 5 shows the plot of the two temperatures versus time. The two temperatures drop from 12 to −11°C, and the two curves are very close to each other. To highlight the difference in the measurements, the Frensor data were subtracted from the reference data, multiplied by 10, and plotted on the graph. This is the curve that runs mostly above the 0°C line. The figure indicates that the Frensor reports temperatures that are slightly lower than the actual freezing-point temperature. The errors are less than 0.5°C, and since the Frensor underreports the actual liquid freezing point, decisions to add deicing chemicals to the road surface will be fail-safe—that is, made slightly more often than they would be otherwise and ensure the public safety.

SENSOR OUTPUT

The Frensor is connected to a microprocessor controller board when placed into operation. The microprocessor controls the

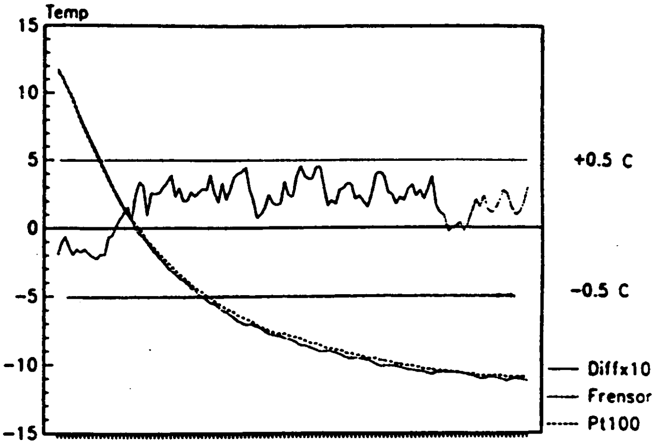

FIGURE 5 Time-versus-temperature plot for Frensor accuracy test.

measuring cycles and processes the signals. During each measurement cycle, the Frensor temperature is first measured and then the Peltier element is cycled seven times. The time required to complete a measurement cycle ranges from 2 min, when the material on the pavement freezes all seven times, to 5 min, for cold, dry pavement.

When the surface is wet, a freezing point is calculated. If there is very little moisture on the road surface or if it is frozen, then the microprocessor may not be able to calculate a correct freezing point. The output is then "moisture" or "ice." Outputs from the controller are both analog current levels and digital as RS-232C.

One notes that when the pavement is covered with material that freezes rapidly and the conditions are most dangerous, the Frensor completes a freeze-thaw cycle in 17 sec, minimizing the chance for errors to occur due to changes during the measurement cycle. Also, as part of the internal programming of the microprocessor, the road condition reported by the Frensor is based on all seven cycles and the reports from the Frensor.

Figure 6 shows data from a 3½-day period in February 1990. The installation consisted of a Frensor, a precipitation detector, a surface temperature sensor, and the microprocessor controller board. The Frensor was located near the tire track on a road with heavy traffic. Highway maintenance personnel recorded observations of the road surface and the application of salt during the period.

The precipitation detector showed precipitation falling on Wednesday and Thursday. The solid curve shows that the surface temperature started near 0°C on Wednesday, dropped to −6°C on Friday morning and then to −9°C on Saturday morning, after which it rose to 3°C.

The Frensor signal was recorded every 30 min. The freezing point of the surface material was reported as 0°C for most of Wednesday and Thursday and −2°C for a short time on Wednesday. It drops to −6°C on Thursday evening and then reports a moist surface through much of the night. During the day on Friday, the Frensor reported freezing points, a moist surface, and ice on the surface. From late in the day on Friday into Saturday, the Frensor reported a dry surface.

The observation logs show that salt was spread on the road at 6 p.m. Wednesday, but freezing conditions still occurred. The salt was diluted by the precipitation. Salt was again spread on Thursday evening. This coincides with the drop in freezing point shown by the Frensor to −6°C. The road surface was fairly dry during this period so that the amount of water in the Frensor cup was so low that it could only indicate "moist."

Snow on the side of the road thawed around noon on Friday and came out onto the road. The Frensor indicated a freezing point of about 0°C. As the road surface dripped during the afternoon and evening on Friday, the Frensor indicated lower freezing points due to the higher salt concentration. A few indications of "moist" and "ice" occurred in cases when the Frensor could not accurately measure the freezing point. The observation log showed that the road surface was dry from Saturday morning to the end of the study period; the Frensor also indicates this.

The Frensor data are used by road maintenance personnel to determine the action needed to keep the road safe. When the Frensor reports that the material on the pavement is freezing at temperatures above the pavement temperature, the road must be deiced. When the material is freezing below the road surface temperature, deicing can be halted. The decision of what action to be taken when there are reports of "moist" and "ice"—as well when to recommend deicing when precipitation continues—should be made by considering the Frensor reports of the road conditions, the weather forecast, and a knowledge of the road and how it has been affected by previous storms.

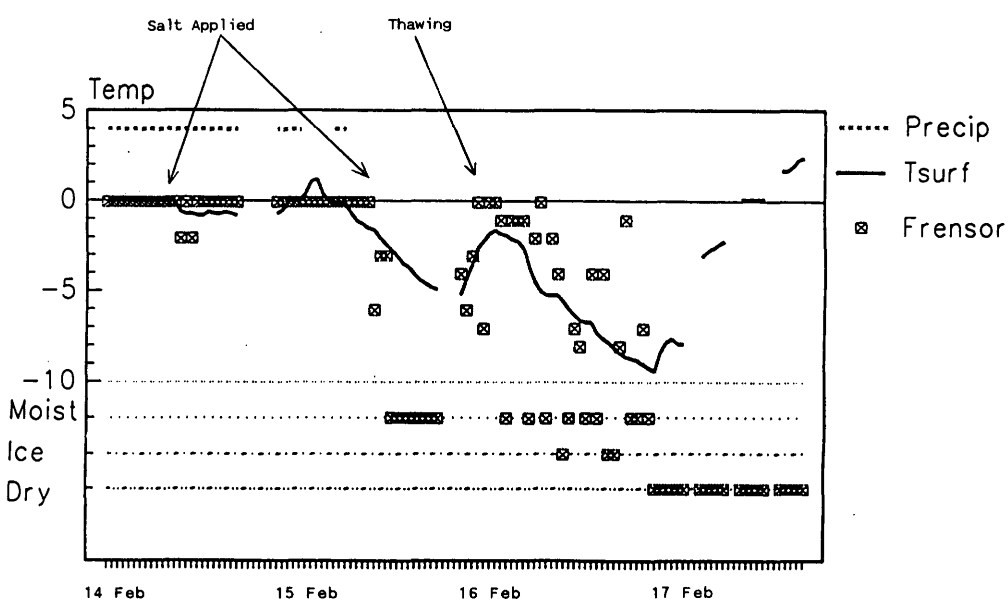

FIGURE 6 Data from 3½ days in February 1990 showing Frensor reports compared with surface temperature data and manual observations.

CONCLUSION

A new solid-state pavement sensor, Frensor, designed to measure the freezing point of moisture on bridge decks, roads, and runways has been presented. Using the Peltier principle as controlled through a microprocessor, the Frensor actively changes the temperature of the moisture deposited on its surface and provides an output of the pavement temperature and conditions. The conditions reported include: dry surface; wet surface; wet, but not frozen; dew; frost; and amount of chemicals on the surface.

The freezing point is measured to an accuracy of ±0.5°C, over a calibrated range of −27° to 0°C. Thus, the Frensor provides a direct measurement of the freezing point temperature of the material on the pavement, with which chemical application decisions can be made.