A Detection System for Frost, Snow, and Ice on Bridges and Highways

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The twofold problem of detecting frost, ice, and snow conditions on the deck areas of highway bridges and overpasses, and providing suitable warnings to motorists has become an increasingly important and critical highway safety problem on high-speed Interstate highways. The author describes a system developed by Holley Carburetor Co. that detects these conditions through the use of a combination ambient air and relative humidity sensor on the bridge railing along with two other sensors buried in the bridge deck. The results of a 3½-year evaluation program of the system that actuates a flashing sign on the Flint River bridge on I-75 near Flint, Michigan, are described.

The paper also introduces a new dual-channel detection system for frost, ice, and snow. This system splits the anticipatory frost and the snow and ice signals into two separate signals. The anticipatory signal can be relayed as an early warning to alert maintenance staffs to send an observer to examine the conditions firsthand and pass a judgment on the need for chemical application or sign actuation. The early warning signal can also be used to switch-on electric heaters embedded in the deck. The separate ice and snow signal can be used to actuate a warning flasher. Also mentioned are two new applications of the dual-channel system on highways as the first application of a similar system on an airport runway.

•THE FORMATION of frost, snow, and ice on the road surfaces of highway overpasses and bridges presents a real driver safety problem. This is caused mainly by initial freezing that occurs only on surface not in contact with the ground. As a result, the motorist is totally unprepared for the slippery pavement areas and is usually traveling too fast to cope with them. The pileups on bridges and overpasses that occur when a single motorist loses control of his car are monumental and a matter of record.

In 1964, engineers at Holley Carburetor Co. developed an anticipatory system for detecting the formation of ice on the inlet surfaces of stationary gas turbines. This system prevented ice formation by directing hot air to the inlet surfaces of the turbine only when ice conditions were present. Because the direction of hot air to the inlet surfaces cuts turbine efficiency by up to 15 percent, the system served the dual purpose of preventing ice formation and keeping turbine operating efficiency high. These patented systems use an ambient temperature sensor and a unique relative humidity sensor to monitor the ice-forming conditions. More than 100 Holley gas turbine, ice-detection systems are operating successfully today.

THE HIGHWAY ICE-DETECTION SYSTEM

Success with the gas turbine, ice-detection system led Holley engineers to develop an anticipatory system of a similar type that could be applied to detect frost, snow, and ice conditions on highways. This system (Fig. 1) consists of a humidity and ambient temperature sensor that is mounted on the side of the bridge railing near the deck.

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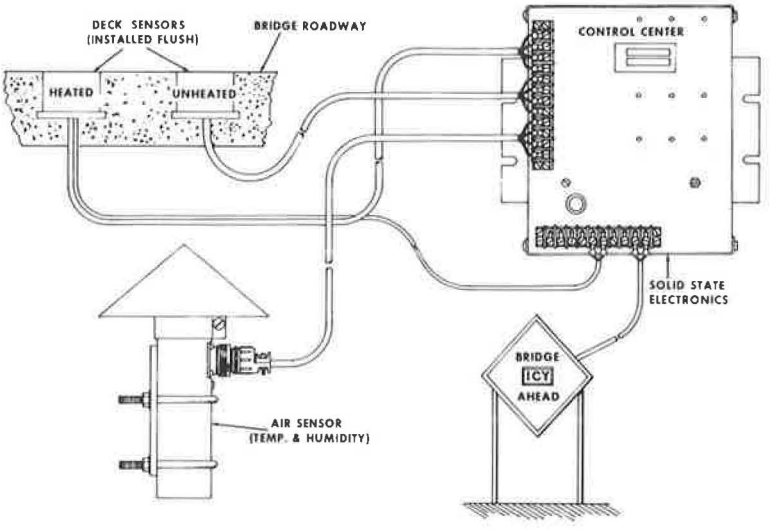

Figure 1. Schematic diagram of the ice-detection system.

Two deck sensors are embedded in the bridge deck flush with the surface. Sensor connecting cables are strung in conduit and connected to a control center mounted near a power supply below the bridge. Output terminals from the control center are connected to lines leading to electric warning signs that flash a BRIDGE ICY signal to the motorist.

The all-solid-state, weatherproof control center includes an amplifier, freezing temperature reference, relative humidity reference, comparators, and a relay that closes to operate the warning sign. The system operates from an 85- to 130-volt, 60-hertz, single-phase electric power source. It has a continuous 1.5-watt power absorption and a momentary absorption of 30 watts. It operates in a range of -55 to +160 F. The temperature and humidity settings are adjustable. The temperature readout is from -40 to +130 F. Humidity readout is from 60 to 100 percent relative humidity. The relative humidity sensor has a humidity-sensitive film deposited on a conductive grid.

HOW THE SYSTEM WORKS

The system has both anticipatory and ice-formation modes. If the bridge deck temperature equals the saturation temperature of the air, condensation of water vapor will occur on the deck surface. When the temperature falls below the saturation temperature, condensation is accelerated. If the deck temperature is at or below 32 F, ice will form. The saturation temperature (the equivalent of 85 percent relative humidity) is calculated to be 3.1 F below the ambient temperature.

By comparing the differential temperature between the ambient and deck surface, the system predicts when frost will appear on the deck. Setting the electronic logic to take action when the relative humidity to saturation differential is slightly larger than the deck to ambient temperature differential enables frost to be anticipated before it forms. Three input signals are combined to activate the anticipatory portion of the system: (a) a bridge deck temperature of 32 F or below, (b) a bridge deck temperature at least 3.5 F below ambient air temperature, and (c) a high relative humidity.

Precipitation can also occur on a bridge deck when humidity is low, and ice could form if the deck is at freezing temperature. This condition would not be detected by the anticipatory system, but is monitored by two sensors flush-mounted in the deck. One sensor has a thermistor-regulated heating element to maintain its temperature at 38 F or higher. The other sensor is unheated and measures deck surface temperature. These sensors function because of the conductive phenomenon between ice and water.

Figure 2. Electric flasher that warns of icy conditions on highway overpasses and bridges.

Figure 3. Location for the temperature- and humidity-sensor unit on a bridge railing.

Water has a high conductance whereas ice has a low one. To sense this difference, ach sensor has two sets of cylindrical electrodes with a gap between each electrode.

When freezing rain or snow occurs, and ice builds up on the deck surface, the unheated sensor has ice between its electrodes, providing low conductance. The heated sensor has water between its electrodes and signals a high conductance. Thus, a conductive imbalance occurs between the two sensors and an icing signal is generated. When salt or other freezing-temperature reduction media are applied for de-icing of the deck surface, the ice on the unheated sensor melts, conductive balance is restored, and the icing energizing signal is removed. The ice-formation signal requires two input signals to be initiated: (a) a bridge deck temperature of 32 F or below, and (b) a conductive imbalance between the deck sensors.

Figure 4. Installations of the ice-sensor units in the bridge deck surfaces.

THE INITIAL SYSTEM EVALUATION PROGRAM

In 1964, the first Holley ice-detection system was installed on the Flint River bridge on I-75 near Flint, Michigan. This system (Figs. 2, 3, 4, and 5) actuated a warning sign. It included a set of recorders that kept a record of ambient temperatures and relative humidity readings as monitored by the detection system, as well as a record of sign actuation.

Figure 5. Location of the power supply and control center on the Flint River bridge application on I-75.

Figure 6. Control center and sensor units for the new dual-channel detection system for frost, snow, and ice on highway overpasses and bridges.

In this $3\frac{1}{2}$-year evaluation program, the recorded temperature and humidity readings were correlated with those of the U.S. Weather Bureau recorded at the nearby Bishop Airport in Flint, Michigan. The reliability of the system's records of temperature and humidity and of its sign activation was excellent. Accuracy of temperature readout for the system is now specified at ± 1 F. Relative humidity readout accuracy is ± 2 percent.

Many highway officials have found over the years that accidents cannot be prevented by signs alone, no matter how they are designed, built, installed, or operated. In the case of slippery highways, the correct solution is probably to examine the condition and to get rid of the frost, ice, or snow. As a result of these recent safety interpretations by highway officials, a new dual-channel system has been developed (Fig. 6).

THE NEW DUAL-CHANNEL SYSTEM

The new dual-channel system for frost, snow, and ice detection has the capability of splitting the warning signal to differentiate between a frost condition and an ice or snow condition. One signal is generated by the anticipatory portion of the system. The other signal is generated by the snow and ice-formation portion.

The anticipatory signal provides an early warning that can be relayed by radio or other communication means to maintenance personnel who can send an observer to the area to study the condition firsthand. The observer can then judge whether or not to call a crew to apply de-icing chemicals. Provision can also be made, if desired, for the observer to manually actuate a warning flasher. The early-warning signal can also be used to switch on electric heating elements embedded in the deck. The second signal is generated by the presence of ice or snow on the bridge deck and generally actuates a flasher sign to warn motorists of the hazardous driving condition.

The block diagram for the new dual-channel system is shown in Figure 7. All-solid-state components provide system reliability. Two relays provide the individual anticipatory and ice-formation signals.

NEW APPLICATIONS OF THE SYSTEM

The highway departments of both California and Illinois are now installing this new dual-channel, ice-detection system. The Illinois installation is on the Blodgett Bridge on I-55. Airport runways are another application where early detection of frost is needed along with ice and snow detection to provide maximum passenger safety. Airports plan to solve the problem by applying anti-icing chemicals when ice conditions are anticipated. A dual-channel system has now been installed on one of the runways of one of the world's largest airports. It is now undergoing complete evaluation tests, which will be reported at the end of the winter of 1968-1969.

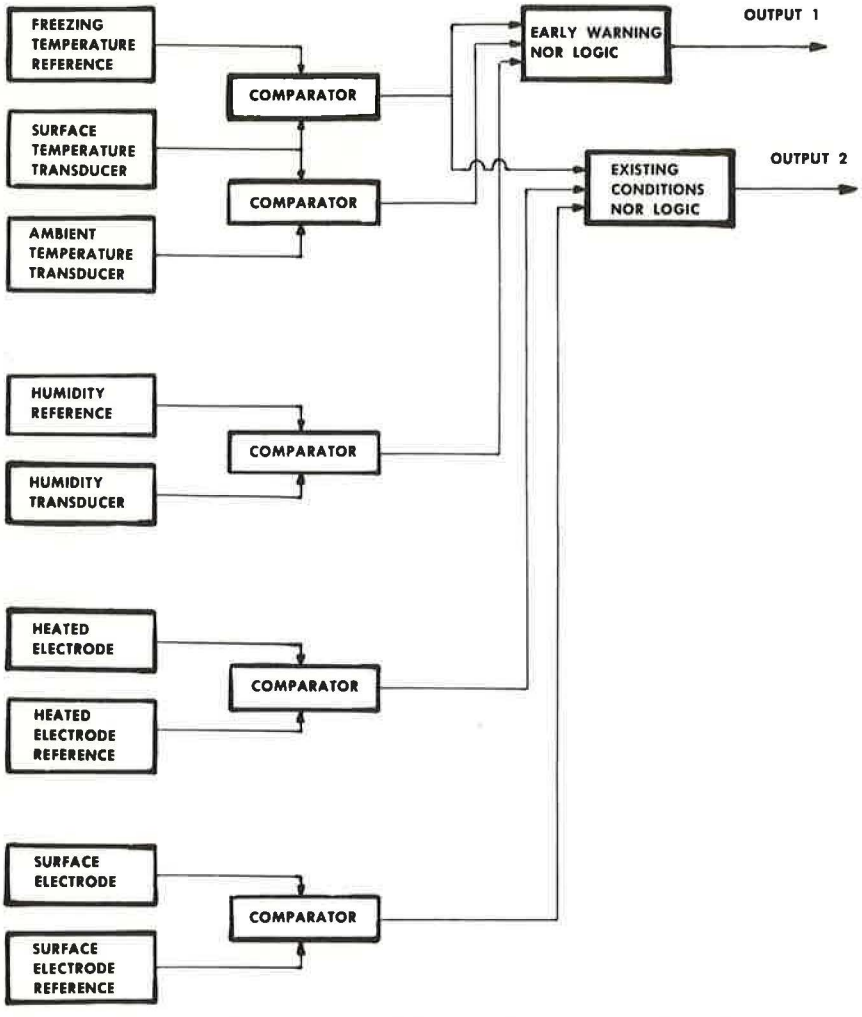

Figure 7. Block diagram for the anticipatory dual-channel, ice-detection system.

Discussion

FOSTER A. SMILEY, Iowa State Highway Commission—Technical progress in both equipment development and highway construction has improved highways to such an extent that travelers expect normal driving conditions on highways in the winter, summer, spring, and fall regardless of the elements of nature. We have gone from slow, antiquated snow removal units to new, high-powered trucks with related snowplow equipment that can quickly and efficiently remove snow and ice from the traveled portion of the highway system.

Regardless of the improvements in equipment and highways, highway maintenance engineers are still faced with one of the same problems that have been with us since the around-the-clock policy for snow and ice removal was established. We still need a reliable method to use so that local maintenance foremen can be advised when the roads are becoming icy and require attention, particularly during the night.

Because bridge surfaces are more susceptible to frost than are pavement surfaces, we developed several rules of thumb to predict the conditions that develop on bridge surfaces in winter weather; but these were not as sophisticated or as reliable as we needed.

Nor did the electronic ice-detecting units that were developed and used to activate lights on signs to warn motorists of ice on bridges seem to be very desirable or practicable because there are over 3,000 bridges on the primary road system in Iowa. It seemed more reasonable to have a system that would warn of an icing condition so that general corrective measures could be taken. In 1964, we decided to use our mobile radio system in some manner to broadcast a message when frost or ice was present. A review of available electronic ice-detecting units indicated that they could be used to trigger a radio transmitter. Although these units were found to be unreliable at times and occasionally became inoperative, they gave us a starting point from which to develop greater reliability and to learn about requirements for maintaining ice-detecting units.

Our first ice detector, an "Econolite" purchased from a Los Angeles company, is installed in a bridge floor on US-30 in Crawford County. The output from this detector is transmitted through a radio transmitter mounted on a utility pole adjacent to the bridge to a mobile relay transmitter of our two-way radio system. The relay repeats the signal so that it is received in the maintenance foreman's home on a special receiver that is activated only by a predetermined signal. The signal is also received by the maintenance mobile unit. The transmitted signal could activate any number of devices such as one that would ring a bell or even turn a bed over. We have taken a more gentle approach and have chosen to broadcast a three-pulse tone once a minute for five minutes of each hour when a slippery condition exists.

In 1965, the department purchased two "Icelert" detector units from Findley-Irvine, Ltd., of Scotland. These units are very reliable in reporting frost, but had to be modified to report packed snow and also to eliminate the signal if a nonslippery salt-brine condition existed. One of these units is in a bridge at the junction of US-30 and US-69 near the south edge of Ames and the other is in a bridge on Iowa-163 at the east edge of Des Moines. After experimenting with and remodeling these units during the winters of 1964, 1965, and 1966, we felt that a reliability of about 80 percent had been achieved. Although this reliability was reasonably good, we felt it must be in the 95 to 100 percent range before it would be acceptable. It is our opinion that when you get a maintenance foreman out of bed at three in the morning, it had better be for a very good reason. We, therefore, began a research project in 1967 to develop a more reliable frost- and ice-detection system for highway bridges. Work on this project is under way and some general conclusions can be made.

In 1967, the department requested information from another state highway department on its experience with the system for frost, snow, and ice detection on bridges and highways, which was developed by the Holley Carburetor Co. and was being used experimentally by that highway department. We reviewed the information furnished and concluded that, although highly sophisticated compared with the Icelert or Econolite detectors, the Holley unit still left something to be desired. Based on the information we have gathered, we would like to comment on the Holley detection system as follows.

The Holley detector device has two noteworthy features. The first feature allows it to predict freezing conditions. The second feature allows it to detect ice and snow directly. Both features perform independently of each other and have separate outputs for signaling purposes.

The prediction of frost conditions is based on the evaluation of ambient temperature, humidity, and deck temperature. An assumption is made that water freezes at 32 F. This would be true if salts (calcium chloride and sodium chloride) were not present on the pavement deck surface. Under these circumstances the predictions would be accurate. In the presence of a significant amount of salts (sodium chloride or calcium chloride), an indeterminate prediction results. Figure 8 shows the freezing point as it is lowered by various concentrations of sodium chloride, NaCl, and calcium chloride, $CaCl_2 \cdot 6H_2O$. In Iowa we have found heavy frost on bridge railings at a temperature of 15 F when there was no frost on the bridge deck itself. This difference was due to the addition of calcium chloride to the bridge surface within the week immediately preceding the observation. Once calcium chloride is on a bridge deck, it is very difficult for frost to form. A high humidity and a very sudden temperature drop, approximately to the 10 to 15 F range, are required for the formation of frost, and under these

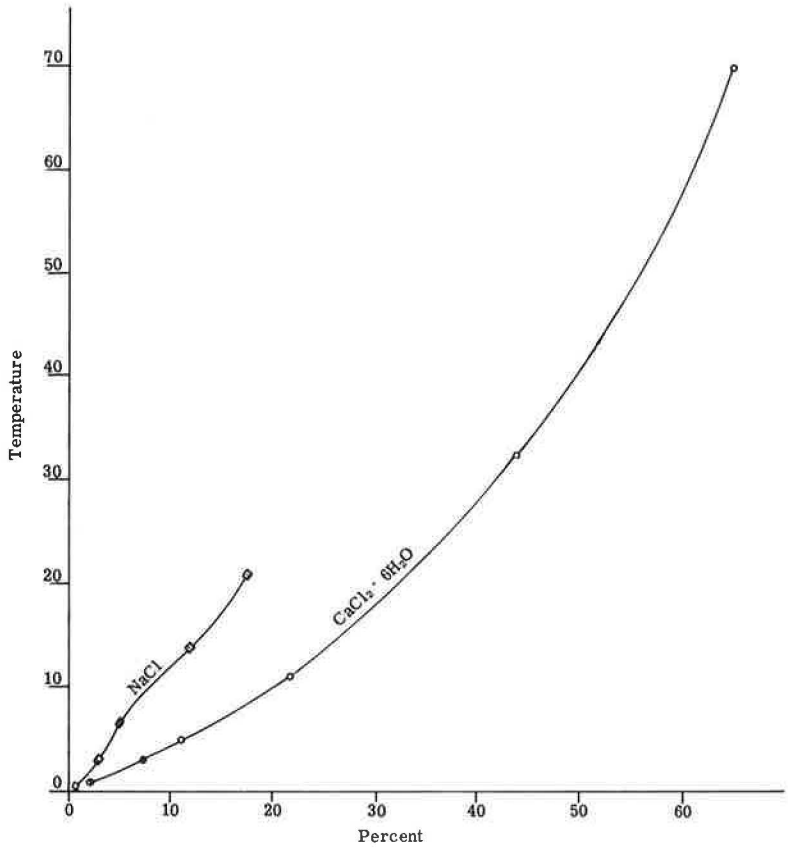

Figure 8. Percentage of salt solids (NaCl and $CaCl_2$) by weight vs degrees of temperature lowering F.

conditions all the theory about radiation of heat from a bridge deck can be forgotten. Based on the description of the operation of the Holley detector, we agree that it would work ideally for the first frost detection of the season. If sodium chloride or calcium chloride were added to remove this frost, however, the succeeding readings could be inaccurate or of questionable value.

The second feature of the Holley detector, the reading of ice and snow directly, is based on the same principle as that used by the Econolite and Icelert detectors. One heated and one unheated transducer embedded in the pavement are compared for conductivity. If water is deposited on both transducers, the conductivity is the same and the output is balanced. If frozen water is deposited on the transducers, the heated transducer will conduct and the unheated transducer will not conduct. An unbalanced output indicates ice. This detection method would be reliable as long as the moisture has a very low salt content, such as that in tap water. However, when the salt content is increased, there is no difference in the conductivity of the frozen water and unfrozen water. After the first frost of the season, the salt content of moisture on the bridge deck becomes unpredictable, and so does the reliability of any output signal that uses conductivity transducers to indicate the presence of moisture, frost, or ice when salts (calcium chloride and sodium chloride) have been applied on a bridge deck.

Regarding the Holley Carburetor Co.'s $3\frac{1}{2}$-year evaluation program, Ciemochowski, states: "Excellent reliability was recorded for the system in temperature and humidity recording as well as sign activation." We are of the opinion that reliability of a frost- and ice-detector system should be related not to the elements of the system, but to the complete operativeness or output of the system—i.e., we would express the percentage

of reliability to be in accord with the following formula:

$$\text{Reliability Percentage} = 100 - \frac{\text{(number of detector errors)}}{\text{(number of slippery conditions)}} \times 100$$

Because of the basic deficiencies of all the commercially available ice detectors on the market today, including Econolite, Icelert, and the Holley detector, the research work done by the Iowa State Highway Commission has concentrated on an approach to the detection of slippery bridge deck conditions different from that which uses the transducers and conductivity cells or both. We are pleased to report that at this time a prototype detector, which is a product if this research work, is installed on a bridge at the junction of US-69 and US-30 near Ames. We feel that, with the experience gained in the 1968-1969 winter season, we will be able to debug our ice-detection system and in another year be able to present information on a detector system that will actually have 95 percent or greater reliability.

MICHAEL F. CIEMOCHOWSKI, Closure—In reviewing the discussion of my paper, I am compelled to clarify some points regarding the operation of the Holley system. These points are as follows:

1. With reference to the discussion regarding two competitive units, I would note that (a) these units have two embedded sensors with a relatively large gap causing sensitivity to be very limited; and (b) because one electrode is heated, it is always above dew point causing the detector to be incapable of detecting frost and to be limited to detecting existing snow.
2. The Holley early warning system monitors humidity, surface temperature, and ambient temperature, and determines the difference between surface temperature and ambient temperature. Humidity may be expressed in terms of differentials of dew point and ambient temperature. Thus, if the humidity differential equals the ambient-surface differential, below 32 F, it means that surface is at dew point and frost will form.
3. A unique feature of the Holley system is the fact that the deck transducers have a very narrow gap. This permits extremely high sensitivity. This gap also possesses capacitance as well as resistive qualities. In the paper, I referred to conductance changes alone for simplicity. However, the detection network is much more complicated. In reality, the change in AC impedance is measured on both electrodes. As a result, the presence of sodium chloride or calcium chloride is detected by these sensors. If an early warning is generated and the presence of de-icing agents is detected, the alert is aborted. For this reason, high resolution differential amplifiers and operational amplifiers are used and not bridge circuitry.
4. The Holley unit, to date, has been based 100 percent on the formula given in the discussion. The early warning, of course, is adjustable and anticipation required, say one hour ahead of actual formation compared to 15 minutes, may materialize or it may not. Thus, long anticipations for accurate alerts are not recommended. In the 15-minute anticipation area, the system is and has been 100 percent correct for the past two years. This is based on actual observations.

I may add that this system has similar performance records in New York, Illinois, California, and Michigan. This year the system has been modified, improving its performance and reliability.