Radio-optical technique for diagnostics of road surface condition

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We propose a radio–optical method for monitoring the state of the road surface. In the optical part, the road surface condition is determined by the depolarization degree of radiation reflected from the road surface. The linearly polarized radiation is directed to the road surface. The paper presents some results of model tests on asphalt covered with snow, ice, and snow–water mixture. The radiowave part of the setup makes it possible to detect the presence of ice under the snow layer.

1. Introduction

The operation reliability of vehicles strongly depends on the road surface conditions (RSC). In this connection it is important to provide a possibility of correctly determining the RSC as well as to forecast the RSC taking into account the naturally changes in the physical processes affecting the RSC. On the whole, the diagnostics of the RSC is a complicated problem. To solve this problem, we must, first of all, define correctly the possible changes of meteorological conditions (weather forecast), physicochemical characteristics of the road, and its specific location. Since, at best, the weather forecast is provided for separate regions, the prediction of the RSC in a particular locality will not be always accurate. Besides, the RSC depends on the traffic intensity.

Taking the above-said into account, the operative diagnostic of the RSC with specialized devices installed at dangerous sections of a road or on a vehicle becomes of great importance. Of course, it is a driver who makes the final decision about the RSC. However, this solution is not always objective, especially in the case of complicated or rapidly varying conditions, for example, under conditions of ice-crusted ground covered with snow or a wet asphalt-covered road.

As present various instruments have been proposed for diagnostic of the RSC that are based on mechanical measurements of coupling characteristics of the road, measurements of electric conductivity of the road surface or combination of measurements of electrical conductivity and the road surface temperature, and other measurements. The suggestions have been made that the electromagnetic waves of radio-frequency range and optical radiation can be used for detecting ice.

For different reasons none of the proposed techniques has been reduced to practice. In our opinion the main reason for that is the ambiguity of the decision made. For example, the values of electric conductivity of the ice and dry asphalt are practically the same that does not enable one to distinguish between these different road conditions only by one parameter. One can readily be convinced that no optical technique can provide for detecting ice under the snow cover, while this road condition is very dangerous. Only several centimeters of snow cover are sufficient for hiding the underlying surface from an optical sensor. There are also other reasons. In particular, the increase of cost of traffic when the RSC data units are set. However, an essential improvement of traffic safety must cover, in our opinion, the supplementary expenses on equipping the transport facilities.

This paper presents a radio-optical technique for RSC measurements. This technique combines the advantages of optical and radiowave techniques and thereby extends the capabilities of RSC diagnostics, it seems reasonable to say that the discussed problem occurs also in the case of diagnostic of the surface of runways at the airports.

2. Optical technique of the RSC diagnostic

The road surface may be thought as a rough surface, whose roughness varies greatly under different weather conditions. The roughness is especially well seen when the road is illuminated. Taking this into account, the problem can be formulated on operative evaluation of the road surface roughness. The use of optical techniques for assessment of surface roughness has been a long–standing problem. Among the optical techniques the polarization ones have major advantages where the road surface is irradiated by a polarized radiation. An overview of polarization techniques in science and engineering may be found in Ref. 7. Some of these techniques can be used for diagnostics of the RSC.

However, for the use of the above techniques special calculations and field measurements under different weather conditions are necessary. But this is the subject of different studies.

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In this paper we present some results of model investigations into this problem. The block diagram of the model setup is given in Fig. 1. A beam of a linearly polarized radiation is directed to the asphalt surface. The radiation reflected from the asphalt surface passes through a lens, a polarization analyzer and is detected by a photodetector, the output signal from which is then recorded with a digital voltmeter.

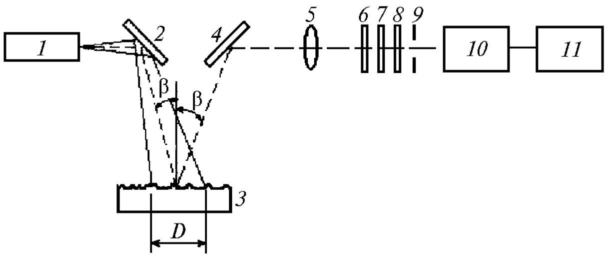

Fig. 1. Block-diagram of the model set-up: laser (*1*); plane mirrors (*2* and *4*); piece of asphalt cover (*3*); lens (*5*); interference filter, neutral density filter, and a polarization analyzer (*6*, *7*, and *8*); aperture diaphragm (*9*); photodetector (*10*); digital voltmeter (*11*).

An LGN–2077B He–Ne laser is used as a radiation source. Specifications of the laser are the following: radiation power is 1 mW, wavelength is 0.63 μm; total angle of divergence is $2.2 \cdot 10^{-3}$ rad; linear polarization 500:1. The photodetector is a photomultiplier FEU–79. The diameter of a beam spot on the asphalt surface is 15 cm, the angle of incidence $\beta \approx 0.5°$. The polarization analyzer installed at a right angle to the beam optical axis, in these measurements, could be turned about its optical axis. Thus, an angular diagram of a degree of radiation polarization reflected from the surface was measured.

The primary goal of optical measurements was to determine the depolarization degree of reflected radiation $N = I_{min}/I_{max}$ depending on the condition of asphalt surface being no less than 30 cm in size. The measurements were performed in an unheated room at a temperature close to the atmospheric temperature, on a clean asphalt cover when its surface was covered with snow, snow–water mixture, and water, which on cooling the surface turned into the ice.

Figure 2 shows the diagram of variation in the polarization degree of reflected radiation $N(\varphi) = I(\varphi)/I_{max}$, under different RSC, depending on the angular position of the analyzer polarization plane measured by the angle $\varphi = 0 - 360°$. The direction 0 – 180° coincides with the polarization plane of laser radiation.

Figure 2 shows a definite relationship between the depolarization degree of reflected radiation and the condition of asphalt surface. Moreover, as one would expect the values of I_{min} are obtained under all conditions of road surface at the angle $\varphi \approx 90°$. There is no need to measure the polarization diagram but it is sufficient to make measurements at angles coinciding with the direction of the laser polarization plane $\varphi = 90°$. The Table 1 presents measured values of the radiation depolarization degree N and the inverse value N_1 for different conditions of the road surface. Thus from our preliminary data it follows that the value N varied within 0.9 – 0.04 (N_1 varies 1.1 to 25). These variations are not so large, but they allow us to distinguish among snow, water, and ice on the asphalt cover. Note that the presence of water ice can be reliably detected that is very important because it causes a particularly dangerous situation for urban transportation.

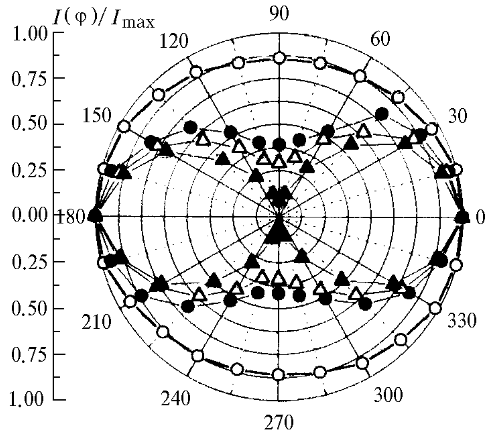

Fig. 2. Angular diagram of polarization degree of radiation reflected from the asphalt cover surface under different conditions of the surface: dry asphalt cover (○); snow (●); wet asphalt cover (Δ); the ice cover (σ).

Table 1. The depolarization degree of reflected radiation

RSC	$N = I_{min}/I_{max}$	$N = I_{max}/I_{min}$
Dry, moist, cooled asphalt	0.40 – 0.33	2.5 – 3
Snow, snow–water mixture	0.90 – 0.70	1.1 – 1.5
Water on asphalt	0.30 – 0.25	3.4 – 4.6
Ice	0.22 – 0.06	4.7 – 15
Ice covered with water film	0.06 – 0.04	16 – 25

It is evident that the optical techniques cannot provide the information on RSC in the case when the road is covered with a layer of some material (for example, snow) where the optical radiation is strongly absorbed or reflected by a surface layer. In particular, as it has already been noted, the ice covered with snow cannot be detected. Under these conditions we propose to use the radio waves.

3. Radiowave technique for diagnostics of the RSC

The detection of water ice under the snow layer on the roads should take into account the following circumstances:

a) the ice is covered with a snow layer of such thickness that when the protectors of car tires contact the ice thus creating the danger of car skidding;

b) the ice is covered with snow of such thickness that protectors do not weigh heavily on it. In this case it makes no difference what is under the snow layer, namely, asphalt, ice or concrete.

In case (a) it is possible to use the radiowave data units.

In our opinion, the most promising are two techniques for obtaining information on the condition of the road surface:

1. The technique used to measure the level of self-excited oscillator generation depending on the resistance inserted in the antenna.

The self-excited oscillator operates in the mode of weak self-excitation. Its contour is loaded by a transmitting antenna. There is a converter coupling between a frequency driving contour and a receiving contour. A transmitting antenna is a half–wave dipole antenna. Depending on the resistance in the antenna its load characteristics vary. Since the self-excited oscillator operates in the mode of weak self-excitation, this results in a change of generation level that, in turn, changes the signal level at the receiving control loaded to an amplitude detector. Therefore over the entire extension of the ice on the road surface a signal will appear, at the output of the amplitude detector, which differs from a signal from the surface free from the ice cover. In modern practice the sensitivity of such data units is the highest when the distance from a transmitting antenna to the road surface being studied is within the limits from 0.1 to 0.2 λ, where λ is the wavelength emitted by the antenna.

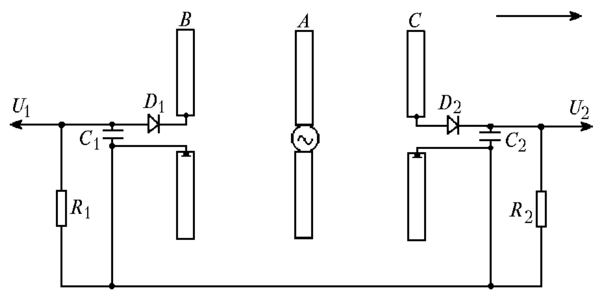

Fig. 3. Block–diagram of the recording technique of the dielectric constant variation at the line separating two media. A is the transmitting antenna, B and C denote the receiving antennas.

2. The technique for recording variations in the dielectric constant ε at the line separating two media.

It is known that if the two receiving antennas B and C are located relative to the transmitting antenna A (see Fig. 3) so that the received signals both of direct passage and reflected from a homogeneous surface after detection would be equal, i.e., $U_1 = U_2$, then, when the sensor moves along the direction shown by the arrow the quantity ε varies stepwise at a boundary between clean asphalt cover and ice-covered road, and the level of a reflected signal received by the antenna C varies stepwise as well. This, in its turn, results in a sharp change of the level U_2 relative to U_1. All these have been detected in our measurements.

4. Conclusions

Comparative analysis performed of the proposed sensor with the known devices has shown that this sensor may be used along with the other devices for diagnostics of the road surface condition. For this purpose it is necessary to integrate the optical and radiowave sensors and to study the specific device operation with simultaneous measurements of coupling characteristics of the road surface and its roughness. It is expected that this sensor will detect dangerous section of a road and conditions of traffic and can provide for necessary information for drivers and (or) a computer for selecting the optimal rate of traffic and the way of using brakes. We do not see any limitations for creation of a radio–optical sensor to be installed on the urban transportation vehicles.

References

1. A.M. Vasil'ev, *Designing of Roads with Taking Account of the Climate Influence on the Traffic Conditions* (Transport, Moscow, 1986), 248 pp.
2. N. Egin, Izobretatel' i Ratsionalizator, No. 9, 16–17 (1984).
3. T. Haavasaja, V. Oy, in: Proc. of the Third International Road Weather Conference (Tampere, 1987), p. 144.
4. Nauka i Zhizn', No. 1, 11 (1995).
5. BMethod and Device for Determination of the Road Surface Condition,BPatent 4300896, Germany, ISM, 1995, No. 19, p. 4.
6. D.G. Baker, D.L. Rusahy, J. Appl. Meteorol. **30**, 387–372 (1991).
7. V.A. Shvets, S.V. Rykhlitskii, Avtometriya, No. 1, 5–21 (1997).