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Vehicle Speed Meters Validation and Verification System

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Introduction

Checking the speed of vehicles on the public road is used as main car accident preventive measure in all countries. These measurements and ticketing are done by the police only. Therefore the various different types of speed meters (radars, lidars, video cameras and others) are used for the purpose [1–4]: handheld speed meters, stationary speed meters, mobile speed meters working in patrol mode, etc. The measurement error of all speed meter used today for traffic control in Lithuania is from 1 km/h to 3 km/h (while speed is below or equal to 100 km/h) [5]. Because of this field of measurements falling within legal metrology scope and therefore being under approval (assessment) body control, all measurement means used in traffic speed check have to pass metrological control and maintenance procedures, which include validation and annual verification. In other words, the police officer can ticket the driver for speeding when the measurements are taken with the approved and verified meter, which maximum permissible error is controlled periodically, only.

Two different principles of validation or verification procedures could be distinguished: indirect method and direct method. The first principle is based on speed meters testing by controlling other parameters (not the speed directly) that meter measures during operation and then calculates the speed value. Lidars, for example, operate measuring distance change over time and then calculating the speed, therefore they are tested by comparing the distance readings to the reference meter (tape-measure, laser distance meters, etc.) value, i.e. indirect method is used for verification. The idea of the second principle is based on object (vehicle, in most cases) speed measurement with meter under metrological inspection and comparison to the given speed of that object or, if the speed is unknown, comparison to reference measuring device speed readings. The last mentioned validation and verification principle is mostly used, especially for stationary meters that have to be verified in their installation place, taking into account the angle between traffic and meter's beam.

As the number of the stationary speed meters is growing, the goal to develop a mobile universal reference speed measurement system that could be used for validation and verification purposes, directly comparing speed meter under test measurement results to reference system measurement results in real time was set. Requirements to the reference system were the following:

- Measurement error ≤ ±0.3 km/h;
- Verification of the stationary speed meters in their installation place;
- Verification of the mobile, handheld speed meters;
- Speed meters field testing for type approval.

It should be noted that all speed meters measure instantaneous speed of the vehicle. As the speed of the vehicle have to be measured with two devices – device under test and reference device – independently during verification, it is necessary to synchronize these measurements in time. Otherwise the results will be incomparable, because of the variation of the speed of the vehicle and therefore the calculated measurement error could not be attributed to the meter under test. The problem complicates speaking about modern stationary speed meters that are designed to control several lanes of the traffic. For example, speed meter PoliScan (Vitronics) uses laser and makes constant scanning of the measurement area, MultaRadar C (Multanova) [6], which operation based on Doppler effect, has wide beam to cover the measurement area. Therefore it is impossible to know at which moment the vehicle will be detected and measurement carried out, in order to measure the speed with the reference system.

To avoid this problem, the method of average speed measurement over the specified length road segment was proposed for the reference system, keeping in mind that this segment of the road has to cover measurement area of the particular speed meter.

The reference system structure, operation principle and measurement uncertainty is presented in following sections.

Reference system structure and operation

As was mentioned before, our research group (prof. R. P. Žilinskas, assoc. prof. R. Dovidavičius, assoc. prof. P. Kaškonas and eng. D. Juodka) took decision to develop a reference system based on average speed measurement, i. e. to measure time interval τ , which vehicle takes to cross the length L road segment, in order to solve the measurement synchronization problem

$$v = \frac{L}{\tau} . \tag{1}$$

It is obvious, that vehicle speed fluctuations will not be taken into account. Therefore the proposed method was the following: the length L road segment is divided to three sections – L_1, L_2 and L_3, applying equation (1) for speed evaluation to the each of them. The vehicle average speed would be

$$v = \frac{1}{3}\left(\frac{L_1}{\tau_1} + \frac{L_2}{\tau_2} + \frac{L_3}{\tau_3}\right) = \frac{v_1 + v_2 + v_3}{3}, \tag{2}$$

where τ_1, τ_2 and τ_3 are the time intervals, that vehicle takes to cross the sections L_1, L_2 and L_3 respectively.

To estimate the speed variation, it is necessary that the following conditions would be satisfied

$$\begin{cases} \Delta v_1 = \left|v - v_1\right| \le \dfrac{\Delta_v}{2}, \\ \Delta v_2 = \left|v - v_2\right| \le \dfrac{\Delta_v}{2}, \\ \Delta v_3 = \left|v - v_3\right| \le \dfrac{\Delta_v}{2}, \end{cases} \tag{3}$$

where $\Delta_v = v_{\max} - v_{\min}$ is the maximum permissible deviation characterizing speed variation value, evaluated as difference of highest and lowest speed of that particular vehicle run.

To determine the maximum permissible deviation Δ_v, the following inequality have to be taken into account

$$\frac{\Delta v_m}{3} \ge U_v(\Delta_v) , \tag{4}$$

where Δv_m is the maximum permissible error of the speed meter under test, km/h; $U_v(\Delta_v)$ is the reference system expanded uncertainty, including vehicle speed fluctuation term, km/h (calculation of Δ_v that satisfy inequality (4) is shown in Fig. 3 and Fig. 4).

Condition (4) says that the expanded uncertainty reference system must be at least 3 times smaller the maximum permissible error of the speed meter under test (requirement of legal metrology). Therefore, if the condition (4) is met, the vehicle speed measurement result is correct and can be used for error of speed meter estimation. On the other hand, if the condition (4) fails, the measurement result has to be rejected, as the vehicle speed over the length L road segment was varying considerably.

Having in mind the presented idea, the reference system was developed and consists of (see Fig. 1):

- Four laser units (S_1, S_2, S_3 and S_4);
- Four channel time interval meter (TIM);
- PC with special software;
- Laser distance meter (LDM);
- Additional aim board, reflector, tripods.

The reference system preparation for operation procedure begins of the placing reference laser beam (that is generated with laser distance meter) in parallel to the vehicle movement trajectory. It must be ensured, that the speed meter (stationary or handheld) measurement zone will be within the controlled segment L. After reference laser beam is in place, four laser units are arranged, starting the arrangement from the last laser unit (most distant from the laser distance meter) in order to keep reference laser beam unblocked. Distances between them L_1, L_2 and L_3 are measured. The structure of the system is shown in Fig. 1.

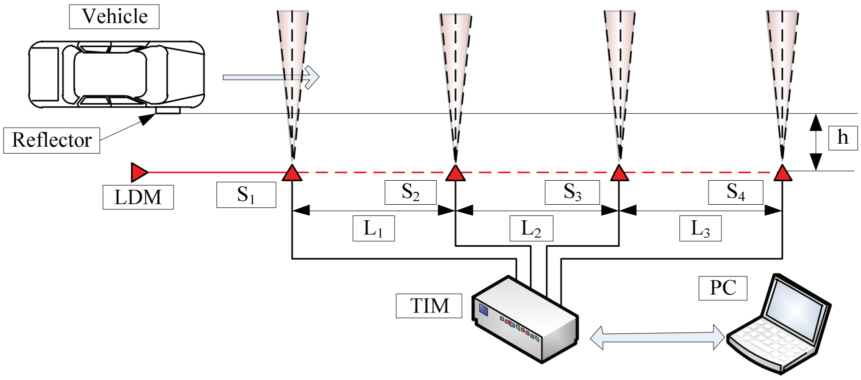

Fig. 1. Reference system structure : L_1, L_2 and L_3 are the distances between laser units; h is the distance from the reference laser beam to reflector moving plane

As the laser sensors are used for beam crossing time moment detection, the parallelism of the beams must be achieved because it influences the measurement uncertainty considerably. The parallelism between the beams of the laser sensors is influenced: 1) by the design of the laser units and 2) by the arrangement of the laser units during reference system preparation.

Therefore design of the laser unit consists of (Fig. 2):

- Laser sensor (see 1 in Fig. 2);
- Laser level (see 2 in Fig. 2);

- Aim board (see 3 in Fig. 2).

The angle between laser sensor and laser level beams is close to 90°; the accurate value of the angle is not important as more important is identicalness of this angle among all four laser units. The identicalness is achieved by calibrating laser units using developed calibration methodology.

In order to keep the beams of laser sensors in parallel during arrangement of the units, two laser beams are under control at the same time: reference laser beam (generated with laser distance meter), which trace have to lay on the aim board vertical line of the laser unit under adjustment and this laser unit laser level beam, which trace have to be on the nearest neighbor laser unit aim board vertical line (or the additional aim board if the adjustment of the first laser unit is taking place).

After arrangement of all four laser units, they are connected to the time interval meter. When vehicle is crossing particular beam, laser sensor detects the reflection and generates pulse signal for the time interval meter. After crossing all beams, PC reads time measurement results τ_1, τ_2 and τ_3 from the interval meter through communication interface and processes the data. The calculation results – average vehicle speed and expanded uncertainty of this particular measurement, including speed fluctuation term, is presented.

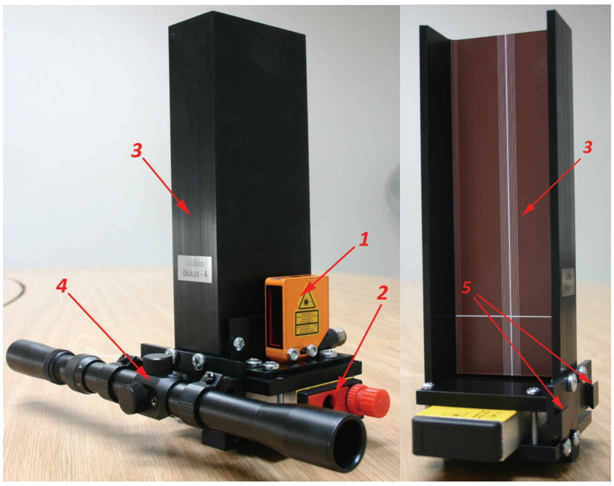

Fig. 2. Laser unit: 1 – laser sensor; 2 – laser level; 3 – aim board; 4 – telescopic sight; 5 – place for telescopic sight

Reference system uncertainty

The developed reference system vehicle speed measurement expanded uncertainty [7], including standard uncertainty of the vehicle speed variation as a separate term, is calculated using expression

$$U_v = 7.2\cdot 10^{-3}\cdot\sqrt{\left(\frac{u_S}{\tau}\right)^2+\left(\frac{S\cdot U_L}{2\cdot\tau^2}\right)^2+\left(80.2\cdot\Delta_v\right)^2}\,, \quad (5)$$

where U_v is the expanded measurement uncertainty, km/h; $\tau = \frac{\tau_1+\tau_2+\tau_3}{3}$ is the average time interval taken by the vehicle to cross each section, s; $S = \frac{L_1+L_2+L_3}{3}$ is the average length between laser units, m; $\Delta_v = v_{\max} - v_{\min}$ is the vehicle speed variation, evaluated as difference of highest and lowest speed of that particular vehicle run, km/h; u_S is the uncertainty term, representing the adjustment of the reference system during preparation procedure. It is evaluated as shown in the expression

$$u_S = \sqrt{2}\cdot\sqrt{\left(\frac{\Delta_T}{2}\right)^2+\left(\frac{h}{\sqrt{3}\cdot S}\right)^2\cdot\left[\left(U_J\cdot S\right)^2+\Delta_{or}^2+\Delta_c^2\right]}\,, \quad (6)$$

where Δ_T is the distance between laser units measurement error (laser distance meter error), mm; h is the distance from the reference laser beam to reflector moving plane, m; U_J is the expanded uncertainty of the angle between laser sensor and laser level beams identicalness measurement (from the calibration certificate of the laser units), mrad; Δ_{or} is the maximum deviation of the laser level beams (traces) of the laser units from the aim board vertical line, mm; Δ_c is the maximum deviation of the reference laser beam (trace) from the aim board vertical line, mm; U_L is the time interval meter expanded uncertainty (from the calibration certificate of the meter), ms.

The expanded uncertainty of the reference system itself is less than ±0.1 km/h, if the following recommendations are met:

- Laser distance meter error $\le \pm 2$ mm;
- The uncertainty of laser units angle identicalness measurement $\le \pm 1$ mrad;
- The uncertainty of time interval meter $\le \pm 0.1$ ms;
- Achieved maximum deviation of the laser level beams (traces) of the laser units from the aim board vertical line $\le \pm 1$ mm;
- Achieved maximum deviation of the reference laser beam (trace) from the aim board vertical line $\le \pm 0.5$ mm.

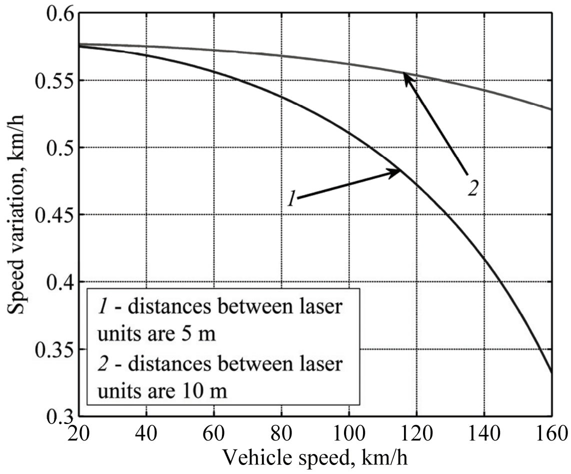

Fig. 3. Maximum vehicle speed variation (to achieve ±0,3 km/h expanded uncertainty)

To verify speed meters, which maximum permissible error is ±1 km/h (Berkut (Olvia) for example [4, 5, 6]), the uncertainty of the reference system have to be ±0.3 km/h and less. Considering that the vehicle runs in the first lane (h =4 m), its speed variation during the verification has to be lower the calculated line, shown in Fig. 3.

To verify speed meters, which maximum permissible error is ±3 km/h (speed is below 100 km/h) and ±3% (speed is above 100 km/h) (Laser traffic measurement system Video-Laveg, speed meter Ramer 7M, stationary speed meter TraffiPhot, etc. [5]), the uncertainty of the reference system have to be ±1 km/h and less. If vehicle runs in the first, second or third lane ($h \leq 10$ m) and other recommendations for the systems preparation procedure (presented above) are kept, then vehicle speed variation during the verification has to be lower the calculated line, shown in Fig. 4.

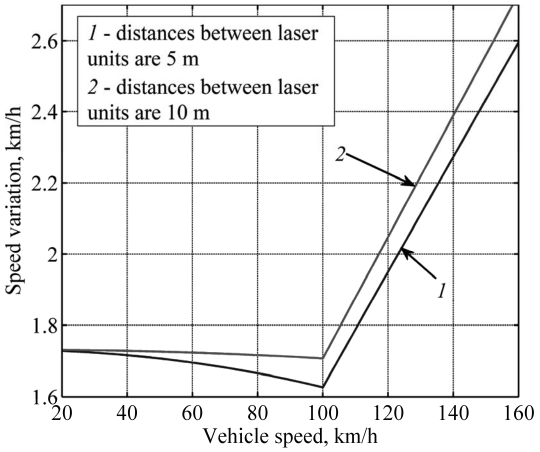

Fig. 4. Maximum vehicle speed variation (to achieve ±1 km/h expanded uncertainty (speed is below 100 km/h) and ±1% (speed is above 100 km/h))

Conclusions

1. Universal mobile reference vehicle speed measurement system was developed. It could be used for validation and verification purposes, directly comparing speed meter under metrological test measurement results to the reference system measurement results in real time, having the calculated expanded uncertainty of that particular vehicle run presented also. It could be used for all types of speed meters (handheld, stationary, etc.) metrological control procedures.
2. Average speed measurement over the specified length road segment method was proposed and realized. Having the measurement area of the speed meter fallen into that segment of the road, the measurement moment synchronization between speed meter and reference system is avoided.
3. The expanded uncertainty of the developed reference system, including standard uncertainty of the vehicle speed variation, while crossing the road segment, as a separate term is less than ±0.3 km/h.

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Speed meters verification principles and problems are observed in the article. Method of vehicle average speed measurement over the specified length road segment was proposed, using four laser units. The method allows to avoid synchronization between measurements of speed meter under metrological test and reference system during verification procedure and therefore to avoid vehicle speed variation influence. Developed reference speed measurement system has expanded uncertainty less than ±0.3 km/h, including vehicle speed variation term. Ill. 3, bibl. 8 (in English; abstracts in English and Lithuanian).

P. Kaškonas, A. Meškuotienė. Etaloninė greičio matuoklių patikros sistema // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 3(119). – P. 95–98.

Straipsnyje išdėstyti greičio matavimo priemonių metrologinės patikros būdai ir problemos. Pasiūlytas vidutinio greičio matavimo tam tikroje kelio atkarpoje išdėstant keturis lazerinius jutiklius, metodas, leidžiantis išvengti patikros metu atliekamų matavimų su tikrinamuoju matuokliu ir etalonine sistema sinchronizavimo problemos, o kartu ir automobilio greičio fliuktuacijų įtakos. Sukurta etaloninė sistema, užtikrinanti mažesnę nei ±0,3 km/h išplėstinę neapibrėžtį, atsižvelgiant į automobilio greičio nepastovumą matavimo atkarpoje. Il. 3, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).