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STATIC METHOD FOR TAXIMETER VERIFICATION

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Abstract:

The purpose of the paper is to represent a method for taximeter verification. Taximeters, as special measurement instruments, are subject to metrological control in order to protect the rights of taxi customers. The methodology applied for the theoretical study of the proposed method is derived from Measurement System Analysis, Root Cause Analysis, and similar taximeter verification methods applied in other European countries. The presented method is innovative for Bulgaria and about to be introduces for the need of metrological control.

Keywords: taximeter, taxi, distance reporting device, sources of uncertainty

1. INTRODUCTION

A taxi is a car equipped with a taximeter that provides paid transportation service to the general public. In this way the distance reporting device becomes subject to subsequent metrological control or verification [1].

The paper [2] classifies different methods for conducting metrological verifications of the taximeters. Three methods were comparatively analyzed and evaluated according to 5 criteria. The basis for the comparison was how the method measures distance. The kinematic method, or taxi on a road section, is ranked last among the three due to various implementation difficulties and practical limitations. The static method, involving the use of a roller test bench and specifically measuring distance by the revolutions of one of the rollers of the test bench, is ranked first among the three due to its feasibility compared to the other two evaluated methods.

The different methods represent the reference distance in different ways. The direct method, or the kinematic one, compares the distance reported by the taximeter by travelling a reference distance by the taxi on a road section. The indirect, or static, method represents the reference distance by counting the revolutions either of a car wheel, or a roller of a test bench.

2. THEORETICAL FORMULATION OF THE METHOD

The method with the use of a roller test bench is accomplished indirectly by setting and reading the revolutions of one of the rollers with a known diameter of the test bench.

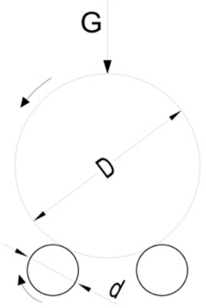

Figure 1: Scheme for distance measurement using a roller test bench and counting the revolutions of a roller

The method implies to compare the distance set and calculated by the roller test bench and the taximeter based on the number of revolutions of the circumferences of the two objects – the roller of the test bench and the car wheel (Fig. 1). The functional relationship between these two can be expressed mathematically:

$$S = p.n = P.N, \text{ or} \tag{1}$$

$$S = \pi.d.n = \pi.D.N, \tag{2}$$

Where,
S – distance,
p – circumference of the roller of the test bench,
P – circumference of the car wheel,
d – known diameter of the roller of the test bench,
n – number of revolutions of the roller of the test bench,
D – diameter of the car wheel, and
N – number of revolutions of the car wheel.

3. UNCERTAINTY SOURCES OF THE METHOD

As the method is theoretically formulated and its elements are defined, it is necessary to analyse the potential sources of error/uncertainty for the method itself. The method, altogether with the roller test bench, the taxi, the operator and the environment, comply a measurement system [3]. The system has to be analysed and its sources of uncertainty have to be identified and quantified [4] [5] [6]. An analysis based on the approach established by Measurement System Analysis is performed for all five elements of the system [3].

The result for the element “method” of the measurement system is presented on a root-cause analysis diagram.

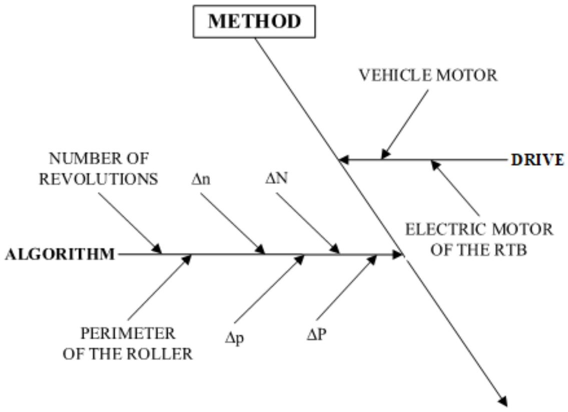

Figure 2: Root-cause analysis of the sources of error of the method [3]

4. MEASUREMENT MODEL

Although the method allows two types of drive modes, in the case of the particular technical solution analysed the emphasis is on a roller test bench driven by its own motor. In this case the distance simulated by the roller test bench to be compared to the reported distance by the taximeter can be expressed theoretically according to eq. (1).

As the roller test bench is driven by its own motor, the circumference of the roller of the test bench, the number of the revolutions of the roller of the test bench and the circumference of the car wheel are the known (measurable) elements of the method. It is necessary to define how they correlate to the number of revolutions of the car wheel:

$$N = \frac{pn}{P} \tag{3}$$

The differentiation of the formula (3) allows us to define the systematic component of the measurement error of the output quantity as follows:

$$N' = \frac{(pn)'P - (pn)P'}{P^2} \tag{4}$$

$$N' = \frac{(p'n + pn')P - pnP'}{P^2} \tag{5}$$

The variation in the number of revolutions of the car wheel is defined by the relations of the circumference of the roller of the test bench, the number of the revolutions of the roller of the test bench and the circumference of the car wheel as given in (6).

$$\Delta N = \frac{\Delta pn + p\Delta n}{P} - \frac{pn\Delta P}{P^2}, \tag{6}$$

Where,

Δp, Δn *and* ΔP – errors/deviations of the input values.

5. DETERMINATION OF THE SYSTEMATIC COMPONENT OF THE MEASUREMENT ERROR OF THE METHOD

The circumference of the roller, p, is calculated based on technical research data that the diameter of the roller is 210 mm, or the circumference is equal to 659.7 mm.

Δp includes two independent errors – the roll diameter measurement error and the elastic deformation error from the perimeter-changing load G. As a result:

$$\Delta p = \sqrt{\Delta p_m^2 + \Delta p_d^2}, \tag{7}$$

Where:

$\Delta p_m = \Delta d_m . \pi$, $\Delta d_m = 0.015\,mm -$ maximum permissible error (MPE) of the measurement of the diameter of the roller [7], and

$\Delta p_d = 0.1\,\%\,.p$ – maximum variation in the circumference of the roller due to natural elastic deformations [8].

Finally:

$$\Delta p = \sqrt{0.05^2 + 0.6597^2} = 0.66\,mm \tag{8}$$

The widely spread basic method for taximeter verification uses measured road section that is 1 000 m long. The same reference distance is used for the determining of the systematic component of the measurement error of the method. The roller of the test bench will make n or 1 515.8 revolutions per 1 000 m.

Therefore, there are 6 evenly spaced points on the circumference of the roller to count its revolutions. The discretion of the revolution counting of the roller is Δn and equals 1/6 of its circumference.

For the needs of this research, an analysis of the most common tyre sizes in taxis has been done. The mode of the research data is the size 195/65 R 15. The diameter is calculated according to a formula [9] and in this case it is 634.5 mm. Thus, the circumference P of the car wheel as a mode is 1 993.3 mm.

The deviation ΔP occurs as ΔP_d because of the error due to the elastic deformations caused by the load G changing the perimeter. The maximum variation in the circumference of the car tyre due to natural elastic deformations, calculated as the methodology in [8] is:

$$\Delta P_d \cong 0.22\,\%\,.P = 4.4\,mm \qquad (9)$$

Then, the systematic component of the measurement error of the method is as follows:

$$\Delta N = \frac{\Delta p n + p \Delta n}{P} - \frac{p n \Delta P}{P^2} \qquad (10)$$

$$\Delta N = \frac{0.66 \times 1\,515.8 + 659.7\ \times 1/6}{1\,993.3} - \frac{659.7 \times 1\,515.8\ \times 4.4}{1993.3^2} \qquad (11)$$

The result of the calculation is a variation of -0.55 revolutions of the car wheel.

Thus, the maximum variation of the measured distance, which can be part of the error of the method, is 1 096.3 mm (or almost 1.1 m for a reference distance of 1 000 m).

Practically, ΔP is formed under the influence of two independent errors – the error ΔP_m from the change in the diameter of the tire as a result of wear and the error ΔP_d. As a result:

$$\Delta P = \sqrt{\Delta P_m^2 + \Delta P_d^2} = \sqrt{(2.\pi.x)^2 + \Delta P_d^2} \qquad (12)$$

Where:

x is car tyre thread wear; and

$$\Delta P_d = 0.22\,\%\,.P \qquad (13)$$

Dependencies (10), (11) and (12) demonstrate the significant influence of ΔP, and respectively – the wear-out of the car tyre, on the accuracy of verification. After substituting dependency (12) in dependency (10) one can determine the numerical value of the allowable wear-out x_m of the tyre for any specific size. If $x > x_m$, and considering the need to assure the required accuracy of verification, it is necessary to correct the input data used in the calculation.

6. UNCERTAINTY OF THE METHOD

A transition from error approach towards uncertainty evaluation can be made [10]. The first step is to calculate the standard uncertainty for the three sources. The uniform distribution of the input quantities is assumed:

$$u_B(n) = \frac{\Delta n/2}{\sqrt{3}} = \frac{\frac{1}{12} rpm}{\sqrt{3}} = 0.048\,min^{-1} \qquad (14)$$

$$u_B(p) = \frac{\Delta p}{K(p).\sqrt{3}} = 0.35\,mm \qquad (15)$$

$$u_B(P) = \frac{\Delta P}{K(p).\sqrt{3}} = 2.31\,mm \qquad (16)$$

Where coefficient *K(p)=1.1* for confidence level *p=0.95* [11].

The next step towards calculating the uncertainty of the method is to calculate the sensitivity coefficients of the three sources of uncertainty defined – the variations in the circumferences of the roller and the car wheel, and the variation in the revolutions of the roller [11] [12].

$$|C_n| = \left|\frac{\partial N}{\partial n}\right| = \frac{p}{P} = \frac{659.7\,mm}{1993.3\,mm} = 0.331 \qquad (17)$$

$$|C_p| = \left|\frac{\partial N}{\partial p}\right| = \frac{n}{P} = \frac{1515.8\,rpm}{1993.3\,mm} = 0.76\,mm^{-1}.min^{-1} \qquad (18)$$

$$|C_P| = \left|\frac{\partial N}{\partial P}\right| = \left|\frac{-np}{P^2}\right| = \frac{1515.8 \times 659.7}{1993.3^2} = 0.252\,mm^{-1}.min^{-1} \qquad (19)$$

The combined standard uncertainty u_c of the measurement method is:

$$u_c(N) = \sqrt{C_n^2 u_B^2(n) + C_p^2 u_B^2(p) + C_P^2 u_B^2(P)} = \qquad (20)$$
$$= \sqrt{0.331^2 0.048^2 + 0.76^2 0.35^2 + 0.252^2 2.31^2}$$

$$u_c(N) = 0{,}64\,min^{-1} \qquad (21)$$

In this specific case, if the perimeter of the tyre of the verified car is p = 1 993.3 mm, then the combined standard uncertainty will be 1 275.7 mm (1.28 m) for a reference distance of 1 000 m.

7. SUMMARY

- The measurement equation of the static method with the roller test bench for conducting metrological verifications of the taximeters is defined.
- The systematic component of the measurement error of the method is determined. Presented is dependency for maximum wear-out of the car tyre for the needs of the metrological verification.
- Uncertainty of the measurement method is determined.

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