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UNCERTAINTY OF BRAKING PARAMETERS MEASUREMENTS BY VEHICLES TECHNICAL INSPECTION

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Abstract: Now-a-days more widely is taken to use the road vehicles periodical inspection with aim to have knowledge of the technical level of item and to assure the safety. To have the assured right inspection results there shall be used various testing and measurement procedures. Among of the important are measurements of the parameters showing the road vehicles brakes correct operation. To give proper conformity estimation to the vehicles brakes operation shall be used uncertainty of measurement result. To give more confidence to the estimated uncertainty components suitable way is to carry out measurement comparisons of brakes parameters.

Keywords: Measurement, uncertainty, braking parameters.

1. INTRODUCTION

The road vehicle inspection is a process to perform mandatory inspection, including any associated testing, of road vehicles according to the prescribed requirements and to determine the conformity of the inspected vehicles to those requirements, on the basis of a professional judgment. List of items to be inspected and/or tested are prescribed or otherwise specified in the territory where the inspection is performed, such as European Union use directive 96/96/EC. Important are circumstances of the measurements which give to the measurement process stability, correctness and fullness. This involve such aspects like management system, proper use and metrological control of the measuring instruments and validated testing methods and also deep measurement uncertainty estimation.

Road vehicles main parameters for the vehicles inspection are connected with safety and environmental protection. Important are parameters showing the brakes correct working such as braking force and efficiency and equality of braking force of various wheels.

The road vehicles parameters have prescribed permissible error limits. To give proper conformity estimation to the vehicles technical state, shall be used uncertainty of measurement result.

To have stability of the measurement process, there shall be used the assurance of process. Complexity of the assurance of result of the measurement process can involve widely accepted principles like accreditation. To have an accreditation all competence requirements given in standards [1] and some specific requirements depending on concrete object and legal prescription shall be guaranteed by body. Above standard demands also solving the problems combined with the measurement uncertainty.

Above was main origin for this study work and goal was to estimate uncertainty components of the braking parameters measurements and control of those through results gotten from the practical comparisons.

2 NEED FOR COMPETENT MEASUREMENTS ON ROAD VEHICLES

In Estonia was registered about 0,4 million road vehicles. Road vehicles shall be technically maintained and approved if are used on the public roads. Technical inspection shall be carried out through prescribed time period which is one or two years depending on the age of vehicles.

Well known is the vehicle inspection meaning which is a process to perform mandatory inspection, including any associated testing and measurements, of road vehicles according to prescribed requirements and to determine the conformity of the inspected vehicles to those requirements, on the basis of a professional judgment.

Inspection body is a public or private organization authorized by a governmental authority to perform mandatory vehicle inspections. Functioning vehicles inspection bodies are 65 - 67 in Estonia and they all are private companies. Its quantity varies little bit depending on the concrete situation on the market.

By vehicle inspection are used mainly 5 – 6 measurements (see Table 1). One of the most important parameters which shows the vehicles condition are brakes correct working indicators. Those are braking force and braking efficiency and equality/difference of braking force of various wheels on the same axle.

Competent measurements and confirmed equipment shall give basis for the right conformity declaration by inspection body. Such declaration shall not limit vehicles owners legal rights but on the other hand give safety for other participants of traffic.

Table 1. Measurement of vehicles safety parameters with measurement range and theoretical predicted uncertainties

Parameter	Measurement range	Expanded uncertainty, 95 % probability level
Ignition engines exhaust gases	CO content (0,03÷10) vol % CO_2 content (0,5 ÷ 18) vol % CH content (5÷9999) vol ppm O_2 content (0,1 ÷ 22) vol % λ-number (0,8 ÷ 1,2)	0,1 vol% or 10 % from measurement result (MR) 1,0 vol % or 10 % from MR 12 vol ppm or 10 % from MR 0,3 vol % or 10 % from MR 0,3 % from calculated value
Compression engines gases smoke	(0,5 ÷5) m^{-1}	0,5 m^{-1} or 10 % from MR
Braking force and vehicles mass	0,1 kN ÷ 40 kN 100 kg ÷ 15 t	10 % for 1 force measurement 10 % for force difference 3 % for mass
Geometrical measures	0,5 mm ÷ 30 m	0,5 % from MR
Noise by standing	(30÷130) dB	3 % from MR
Window glasses transparency	(5 ÷ 60) % (60 ÷ 100) %	15 % from MR 10 % from MR

Basis for the Estonian legal act for vehicle technical condition is European Union Directive 96/96/EC.

3 REQUIREMENTS FOR COMPETENT INSPECTION BODY OF ROAD VEHICLES

Measurement stability can be assured using management systems. Inspection body shall meet prescribed, especially legal if exists, requirements if it want to be recognized as being competent to carry out mandatory inspections of road vehicles. Internationally adopted standard for competence of inspection bodies is EN ISO/IEC 17020. Second possibility is to use standard EN ISO/IEC 17025 [1] which gives requirements for testing (including measurements) body. In both standards are given management system and technical requirements which are very similar.

To assure stability of the measurements and basis for the conformity declaration, the vehicles inspection body shall tackle next basic technical requirements given in [1, 2]:

- personnel who performs measurements shall have qualification, experience and training;

- shall be used recognized measurement methods which have compliance with legal requirements, if are used non-standardized methods they shall be validated to show that gives right result;

- shall have and use procedures for the uncertainties estimation and documentation on widely accepted principles. Inspection body shall understand uncertainties which are involved by the various measurements. Not enough to use only the measuring instruments deviations. Shall be also dealt with influences arising during the measurement operation. Measurement process result is only estimate of the true value and the interval where true value may be situated gives uncertainty. Essential is above if inspection personnel makes conformity decision. There shall be involved uncertainty. Safety requirements demand that the accepted result shall be less normative value minus uncertainty. But legal requirements allow to accuse person under control only if the measured value is properly assured. Shall be taken into account that uncertainty interval is not properly assured and so it shall be used as suitable for person under sanction i.e. measurement result may overrun normative value by uncertainty;

- shall have all measuring instruments and auxiliary equipment, which are prescribed by measurement methods and such instruments shall be maintained and controlled before use and periodically, vehicle inspection equipment shall have regular in-service functional checks between the programmed calibrations;

- all measuring instruments used by measurements shall be traceably calibrated or verified (if required by legal acts) before use and have proper calibration certificate including uncertainty considerations;

- for computers or other automated equipment used in the vehicle inspection process shall be ensured that software is checked and tested, prior to its release for use and regularly during in-service use, to ensure its adequacy and capability for the intended purpose.

During 2005 in Estonia was carried out by Estonian Accreditation Centre estimation of the competence of road vehicles inspection bodies but only on the measurements area. Involved were 65 inspection stations. During estimation were documented non-conformities related to the standard [1] technical articles and most important were as prescribed as follows:
- control of measuring instruments was not regular and the maintenance procedures were not confirmed for intermediate period of calibration;
- uncertainty of measurements was not estimated and used, but measurements were complicated and exist plenty of the influence factors;
- measuring instrument indication was taken as the true value of measurement;
- measurement procedures were not documented so that measuring personnel can freely use it.

As positive aspect there was well trained technical personnel who knew technical requirements of the vehicles inspection. Bodies were equipped with modern equipment and environmental conditions for working were good. During estimation were non conformities corrected by bodies but the role of management system was not deeply understood.

During competence estimation was carried out practical measurement comparison for braking parameters and environmentally and for health dangerous exhaust gases content.

4. MEASUREMENT OF VECHICLES BRAKING PARAMETERS

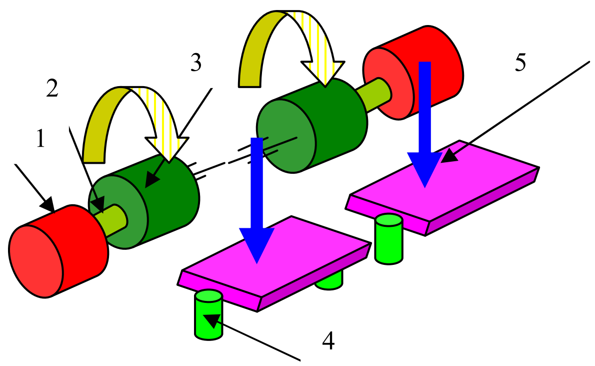
4.1. Principles of measurement

To show correctness of vehicles braking shall be measured braking force on every wheel, difference of braking force of various wheels on the front and rear axles (separately for main brake and parking brake) and braking efficiency. For efficiency calculation shall be weighed mass of vehicle.

Vehicle inspection station shall have available for use for the braking parameters measurement following equipment according to [2]:

- weigh-bridge or other weighing equipment;
- roller brake tester (roller bench);
- manometer, appropriate for measuring air pressures in pneumatic brake systems and in tires.

Braking parameters are measured directly on roller bench with weighing instrument which principle of working is shown on Figure 1 and its required parameters in [3]. Weighing device may be built under rollers.



Devices codes identification: 1 – Force giving device 2 – Force measuring cell 3 - Roller 4 – Load cell 5 – Load receptor

Fig. 1 Roller bench with weighing device for braking parameters measurement

Braking parameters measurement process is rather complicated and has various influence factors which shall be tackled during the uncertainty estimation. Some ultimate points are given as follows.

Road vehicles braking depends on some specific moments. Firstly, from measurement process characteristics like a value of force and speed, smooth and stability of braking force application. Second group of moments is the vehicles condition in time of measurement which involves the vehicles braking system conditions, especially brakes discs and system working conditions like temperature and dryness and the tires clearness. Third group of influence factors is related with the roller bench and the weighing instrument conditions – roughness, dryness and vehicles exact localization on rollers. Last group is tackled with measurement person competence – how quickly, smoothly and forcefully they carry out braking action.

4.2. *Main characteristics*

Based on measurement results road vehicles braking main generalized parameters can be calculated using next equations.

Difference of the braking force of wheels on the same axle F_D is calculated using equation (1):

$$F_D = \frac{F_{LW} - F_{RW}}{\left(F_{LW} + F_{RW}\right)/2} \cdot 100\ \% \qquad (1)$$

where F_{LW} and F_{RW} are the measured braking forces on various wheels (left and right) on the same axle.

Separately are calculated difference for front and rear axle and for parking brakes.

Braking efficiency for vehicle E_B is calculated using equation (2):

$$E_B = \frac{F_{SF}}{M_{SV}} \cdot 100\ \%, \qquad (2)$$

where F_{SF} is the summary braking force for vehicle and for finding of it are summarized braking forces of all four wheels and M_{SV} is the summary mass of vehicle. Braking efficiency is calculated separately for main brakes and parking brakes.

5. UNCERTAINTY OF MEASUREMENT

5.1. *Uncertainty estimation*

For this study work were used GUM principles for estimation of the uncertainty components. Components estimation was carried out using concrete measuring equipment data and methods and conditions.

Essential for the vehicles braking parameters measurement is fact that great number of the influence factors exist and some of them can give exaggerated uncertainty if were not correctly limited. Influence factors summary quantity can reach up to 6 – 8.

Main technical components involved by braking parameters measurements are measurement method, measuring instruments, item e.g. vehicles parts having importance for braking correctness and external condition and also persons carrying out testing. Above shall be used as giving components for the measurement process uncertainty estimation.

5.2. *Theoretical values*

Through authorities requirements are given allowed values for difference of braking force of various wheels on the same axle and for braking efficiency. For main brakes the difference must be less than 30 % and efficiency more than 50 %. They can measured using roller-bench which have expanded uncertainty 2 % (% as difference value for indication) for difference. Practically calibrated is only measurement of braking force separately for left and right roller (Fig 1) with expanded uncertainty 3 % (as relative % value from indication). Weighing instrument has expanded uncertainty ca 0,5 % (as relative % from indication).

Theoretically the measurement uncertainty should be 3 up to 5 times more than measuring device uncertainty. By reason that the braking measurements procedure is complicated we can assume expanded uncertainty for braking force difference measurement as 2 % × 5 = 10 % ((% as difference value for indication). Uncertainty for efficiency measurement using Equation 2 and force measuring device uncertainty 3 % four times and balances uncertainty 0,5 % (twice measurement, both axles separately) and assuming process complication should be up to 30 % (% as relative value) from calculated value or 15 % as absolute value for efficiency 50 %. Results are given in Table 3.

To estimate more correctly the relation between measuring instrument and measurement process uncertainty shall be found the sensitivity coefficient of influence factors. In initial stage we can give only rough estimation of them and they were further controlled as summarized value through measurement comparisons. There was also lack of equipment producers data. Influence factors are as next:

- a speed and stability of braking force application;
- the vehicles braking system and discs working conditions;
- the tires clearness;
- measuring instruments calibration uncertainty;
- brake tester rollers surface roughness and dryness;
- weighing bridges stability;
- vehicles wheels position variation on rollers and on load receptors;
- temperature and cleanness of the working environment;
- testing persons - competence to carry out on a similar way procedures.

An average component uncertainty value can assume to be on the level (1 to 3) % from the indication.

6. PRACTICAL COMPARISON OF MEASUREMENTS

6.1. Organization and handling

Estimation of rightness of theoretical results were controlled through practical measurements as comparisons in the road vehicles inspection stations. To assure the comparison results for comparison were used ISO Guide 43 principles.

Practical measurements for the comparisons were carried out on the time period from April up to September 2005. Four road vehicles were used and involved were 53 Estonian inspection stations for the road vehicles and 61 roller benches. For the assurance of equal conditions were used means giving stability of comparison object and to limit the extreme measurement influence factors. There was plenty of influence factors but all can't to be equally minimized. Other hand positive moment was, that such conditions gives more or less real measurement situation and gives possibility to have an average value which is on the level of expanded uncertainty for Estonian measurements in this area.

Problems which shall be taken account and solved so that influence was on minimal level were:
- comparison object stability assurance, time interval was long, up to 5 month and vehicles were in used during this time period and distance was up to 4000 km, controlled trough results on Figures were every drift can be viewed,
- exist no possibility to have a reference values for controlled parameters, estimation only on statistical bases;
- measurements were carried out by station personnel, style was various;
- environment influence various, temperatures variation from 5 °C up to 20 °C and ventilation various for exhaust gases measurements;
- measuring instrument maintenance, can be influences from previous measurement.

6.2. Results

Braking parameters measurement results are given in Table 2. As example shown is only one vehicles data.

Using measurement data of comparison are calculated main general characteristics for uncertainty estimation. Found characteristics are: general mean $\overline{X}$, median *Me*, minimal and maximal values in the set (except outliers), standard deviation s_{ra} if expected would be rectangular distribution, standard deviation s_n if expected would be normal distribution, estimated expected deviation (realistic through practice value) Δ_{rp} on probability level P = 95 % taking account both standard deviations. For Δ_{rp} was used the expert estimation founding an average value taking account standard deviations and min and max values related to the mean value.

Table 2 Braking parameters measurement initial results and calculated values for vehicle No 1

Date	Braking force diference F_D			Mass M_{SV}	Braking efficiency E_B	
	Front	Rear	Park		Sum	Parking
	%	%	%	kg	%	%
04.03.05	2	38	31*	1310	64	28
28.04.05	-3	44	-7	1285	68	35
09.06.05	-2	40	12	1266	59	30
01.07.05	8	39	17	1315	57	28
07.07.05	-13	49	-4	1330	60	29
07.07.05	-2	58	5	1270	58	29
13.07.05	-9	41	9	1220	61	28
13.07.05	-7	49	16	1240	58	26
13.07.05	5	43	10	1320	58	33
14.07.05	3	48	12	1280	60	24
05.09.05	-9	57	-15	1351	68	30
07.09.05	-13	52	-3	1260	52	25
07.09.05	-1	57	-11	1441	61	29
Calculated parameters						
Mean X	-3,2	47,3	3,4	1299	60	28,8
Median *Me*	-2,0	48,0	7,0	1285	60	29,0
Min	-13	38	-15	1220	52	24
Max	8	58	17	1441	68	35
Rectangular stand deviation, *s*	5,8	5,6	8,9	61	4,4	3,1
Normal, s	6,7	7,1	10,95	57	4,4	3,0
Realistic deviation, $\pm\Delta_{rp}$	11	11	8	120	8	6

* Handled as outlier

Based on above results are calculated average characterizing parameters taking account all four vehicles. Those summarized results are given in Table 3. In the end part of Table 3 are shown theoretical value and summarized, probable value trough comparison assured, expanded uncertainty of braking parameters measurements.

The Table 3 show that theoretical uncertainty estimation is a bit better than practical measurements gave. Above means that the measurement uncertainty is better to estimate 6 times bigger than the measuring device uncertainty in the case of force difference estimation.

Table 3 Braking parameters measurement comparison summary results for 4 vehicles

	Force difference, F_D			Mass	Efficiency, E_B	
	Front	Rear	Par-king	M_{SV}	Sum-mary	Par-king
	%	%	%	kg	%	%
Standard deviation , rectangular distribution, s_r						
Vehicle1	5,8	5,6	8,9	61	4,4	3,1
Veh 2	5,8	13,3	15,8	45	6,1	6,9
Veh 3	7,3	9,7	23,6	89	4,7	3,9
Veh 4	6,6	6,7	8,3	72	7,5	3,1
Standard deviation, normal distribution, s_n						
Vehicle1	6,7	7,1	13,0	57	4,4	3,0
Veh 2	4,8	12,4	14,5	37	5,5	5,0
Veh 3	9,8	10,4	28,1	100	5,9	4,8
Veh 4	6,9	5,7	7,8	58	7,3	3,0
Estimated deviation on probability level P=95 %						
Vehicle1	11	11	16	120	8	6
Veh 2	10	17	25	80	11	12
Veh 3	14	18	42	170	10	8
Veh 4	12	12	16	125	14	6
Probable in practice, Δ_{rp}	12	17	25	130	13	10
Theoretical	10	10	10	75	15	10

On the four Figures are visualized measurement data from Table 2. As example is shown only one vehicles data but similar outlook had also other three vehicles results.

Fig. 2 shows braking force difference for vehicle No 1: front axle wheels, rear axle wheels and parking (rear axle wheels). From the figure can observed, that little drift exist for the vehicles rear axle brakes. For the other cases not found some systematic influence, results have random up and down movement. Horizontal axle shows bodies number and also time.

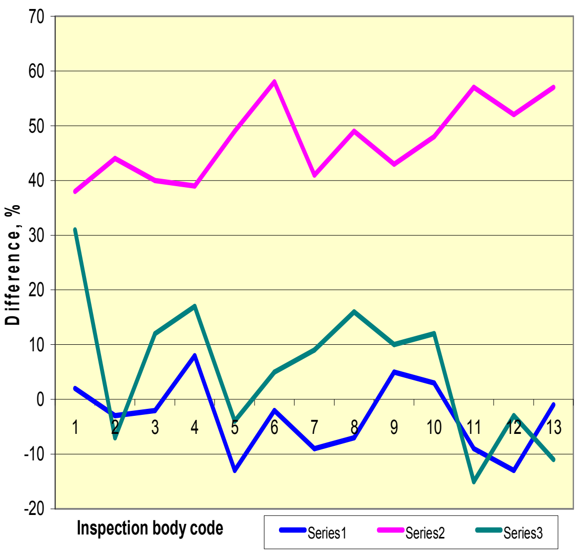


Fig. 2 Braking force difference for vehicle No 1: front axle wheels (series 1), rear axle wheels (series 2) and parking (rear axle wheels) (series 3)

Fig. 3 shows braking force efficiency for vehicle No 1, summary and for parking brakes. From the figure can observe, that not found some systematic influence, results have random movement.

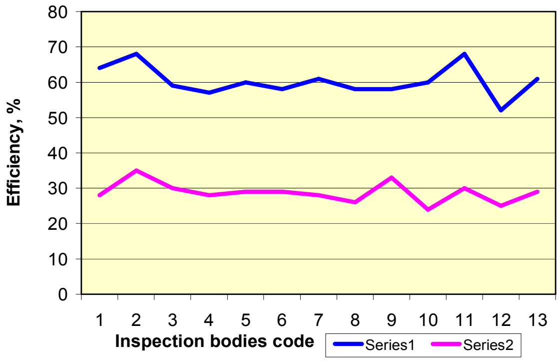


Fig. 3 Braking efficiency for vehicle No 1, summary for vehicle (series 1) and parking (series 2)

Fig. 4 shows vehicles mass measurement for braking force efficiency estimation for vehicle No 1. From the figure can observe, that not found some systematic influence, results have random movement.

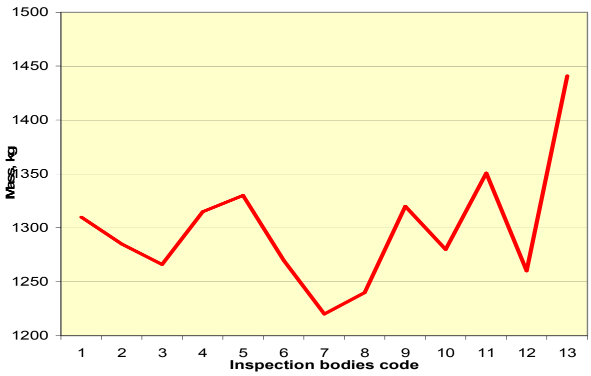


Fig. 4 Vehicles summary mass measurement for efficiency determination, vehicle No 1

7. CONCLUSION

Vehicles braking parameters measurement has some specific moments and those shall be carefully included to the uncertainty estimation. This study gives uncertainty values and confirms uncertainty estimation results through practical measurement comparison. Study show that expected theoretical uncertainty is a bit better than practical measurements gave. The uncertainty is better to estimate 6 times bigger than the measuring device uncertainty in the case of force difference estimation.

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