XXI IMEKO World Congress "Measurement in Research and Industry"
August 30 – September 4, 2015, Prague, Czech Republic

CHALLENGES FOR THE CALIBRATION OF AUTOMATIC WEIGHING INSTRUMENTS IN DYNAMIC OPERATION

Oliver Mack [1], Tobias Klein [2], Christian Schlegel [3], Matej Grum [4]

[1] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, Oliver.Mack@ptb.de
[2] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, Tobias.Klein@ptb.de
[3] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, Christian.Schlegel@ptb.de
[4] Ministry of Economic Development and Technology, Ljubljana, Slovenia, Matej.Grum@gov.si

Abstract – In contrast to non-automatic weighing instruments, the calibration of automatic weighing instruments in dynamic mode is less well defined. To fill this gap, the European research project "Traceable calibration of dynamic weighing instruments" has been initiated in order to develop new calibration guides for various automatic weighing instruments. As a starting point for the project, we tried to gather some existing experiences in view of test procedures, calibration routines, modelling and uncertainty analysis.

Keywords: **weighing instruments, dynamic operation, calibration procedure, uncertainty budget, legal metrology**

1. INTRODUCTION

With the development of weighing technology, the number of automatic weighing instruments (AWIs), which carry out measurements in a dynamic mode, has substantially increased. Notwithstanding a generally higher purchase price than for non-automatic weighing instruments (NAWIs), AWIs are more effective and efficient for their users in the long term. Improvements in the accuracy of AWIs mean that they are now used in an increasing number of applications from micro to macro weighing. AWIs are used extensively in the preparation, production and quality assurance of pre-packed products as well as for products whose content or composition is determined by weighing. The total market size for AWIs sold annually in Europe is estimated to be around 35000 instruments [1].

The growing dissemination of AWIs emphasises the need to confirm their metrological quality by calibrations and the determination of their measurement uncertainty. Users of AWIs require a reliable estimation of the measurement uncertainty in order to judge the accuracy of the weighing result. The knowledge of the measurement uncertainty is vital for informed decision-making, e.g. in the case of choosing between automatic and non-automatic weighing instruments for a specific purpose.

Particularly, regulated industries, e.g. producing pharmaceuticals or food, have to meet the requirements imposed by specific laws or regulations like the European directive 76/211/EEC, ISO 9001, Good Manufacturing Practice, and Food Safety Standards.

In legally relevant applications, both AWIs and NAWIs have to fulfil the essential requirements of European directives. For AWIs, the Measuring Instruments Directive (MID) 2004/22/EC applies [2]. Generally, the directives refer to standards or normative documents. The MID is implemented by recommendations of the International Organization of Legal Metrology (OIML).

Within the framework of legal metrology, most European countries have experience in using test procedures defined in OIML recommendations for AWIs and also for NAWIs. In some countries like Spain or Italy, AWIs are not subject to legal metrology and thus alternative procedures have been established.

For AWIs in static operation the calibration procedures, error models and uncertainty considerations based on existing calibration standards for NAWIs can be used, e.g. Ref. [3]. The development of calibration guides for the dynamic measurement mode of AWIs is an ambitious goal. Aiming for this goal, it is important to avoid a scenario where national metrology institutes (NMIs) or other organisations individually develop national solutions for standardised calibration methods. Calibration procedures and uncertainty evaluations need to be harmonised at the European level in order to support a common market and avoid trade barriers.

Thus, the development of calibration methods for dynamic measurements with AWIs is the scope of the project 14RPT02 "Traceable calibration of dynamic weighing instruments" within the European Metrology Programme for Innovation and Research (EMPIR) funded by the European Association of National Metrology Institutes (EURAMET). At the end of the research project which started in summer 2015 we hope to present one or several EURAMET calibration guides for various AWIs.

In a first step, the individual experience and knowledge of national metrology institutes and other national organisations concerning the calibration of automatic weighing instruments in dynamic operation including the respective measurement uncertainty budgets should be brought together. In a second step, it is the aim to harmonise, develop and validate appropriate calibration methods for the selected AWIs, to work out error models for the dynamic weighing process, and to develop uncertainty budgets for both the calibration and the weighing results.

Without claiming to be complete, this publication tries to assist in the first step by summarising some of the existing knowledge, namely test procedures, calibration routines and uncertainty considerations which may be helpful in the development of calibration procedures for AWIs in dynamic mode.

2. AUTOMATIC WEIGHING INSTRUMENTS

In contrast to NAWIs, AWIs perform weighing procedures without the intervention of an operator and continuously reinitiate the automatic weighing process [4]. Thus, they are not confined to the static mode but also offer the possibility of dynamic operation.

There is a growing variety of different designs and measurement principles. Examples are conveyor belt weighers, automatic checkweighers (see Fig. 1), automatic gravimetric filling instruments, automatic instruments for continuous and discontinuous weighing, automatic catchweighers, automatic rail scales, and weight graders for eggs. Besides these stationary AWIs, there are also vehicle mounted types, e.g. front-end loaders. Automatic instruments for weighing road vehicles whilst they are in motion are increasingly used for time-efficient weighing of trucks in the context of trade, supervision, and transport safety [5]. More details on the different types of AWIs may be found in [6].

Fig. 1: Automatic checkweigher (© Mettler-Toledo)

3. UNCERTAINTY CONSIDERATIONS

The quality and reliability of a measurement result is expressed by its measurement uncertainty which is a measure for the accuracy of the result. In order to be accurate, a result has to be both true and precise. Trueness means that the average result of repeated measurements is close to the (inherently unknown) “true value”, i.e. that there is no systematic error or measurement bias. Precision means that the dispersion of measurement values is small, i.e. there are only minor random errors.

Determining the measurement uncertainty, both systematic and random errors have to be taken into account. While the influence of random errors may be reduced by taking the average value of many measurements, systematic errors cannot be decreased by repetition. The uncertainty is determined following internationally recognized procedures, which are laid down in the “Guide to the expression of uncertainties in measurement”, the so called “GUM” [7]. The first step is the establishment of the measurement model which is a mathematical relation between the measurand and all quantities which are involved in the measurement. If the measurement model is known, the uncertainty follows from mathematical procedures.

The quantities to be considered include manifold influences from the instrument, the sample, the measuring procedure as well as external influences. In the case of a weighing scale, instrument-specific factors include e.g. the construction of the instrument and its measurement principle based on load cells utilizing strain gauges, electromagnetic force compensation or vibrating wires. The measuring procedure can be influenced, amongst others, by the user. External influences comprise environmental, mechanical and electromagnetic conditions, see Fig. 2. Because all quantities involved in the measurement have to be considered, the development of the measurement model is a major challenge, even in cases of supposedly simple and well-known measurement principles like weighing.

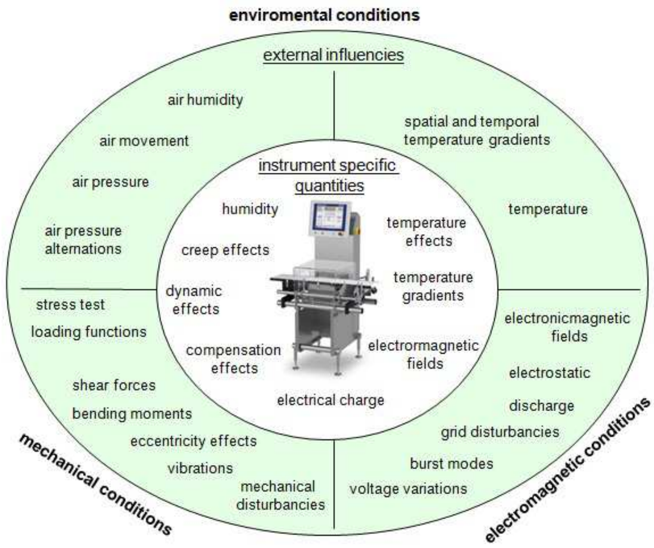

Fig. 2: Possible influences on automatic weighing instruments without any claim of completeness. The chosen distinction between external and internal influences is somewhat arbitrary.

4. CALIBRATION AND TESTING

A calibration is a procedure that establishes a relation between the value indicated by an instrument and the “true value” of a measurement standard. Thereby, uncertainties are taken into account. The aim is to achieve comparability of measurement results from different instruments. Therefore, reasonable conditions have to be stipulated together with the calibration procedure, e.g. in harmonized calibration standards. The calibration procedure should be as close to the routine measurements as possible because a growing deviation leads to growing uncertainties of subsequent every-day measurements.

For example, rectangular or stepwise loading functions typically used in the calibration of weighing scales (see Fig. 3) may not be sufficient. Weighing scales usually show a time-dependent creep behavior after every loading and unloading due to the integrated load cells. Consequently, they may respond differently to the same weight if the loading functions differ, even in the case of static instruments. In the case of dynamic weighing scales, using straightforward static loading procedures is questionable because dynamic effects associated with, e.g. pulse duration, excitation amplitude and frequency of the loading are ignored.

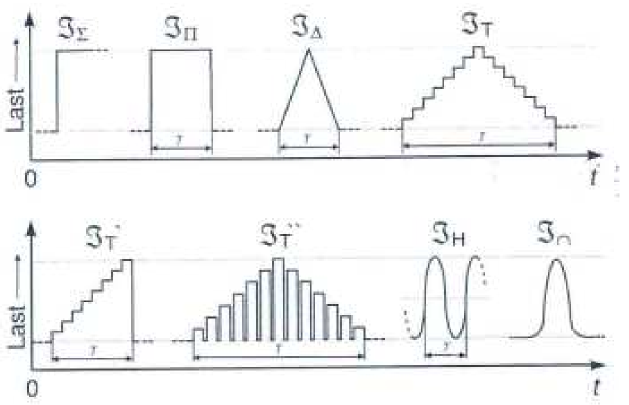

Fig. 3: Typical loading functions used for test and calibration procedures: jump load function, rectangular load function, continuous load function, three types of stepwise load functions, harmonic load function, shock-shaped load function.

The result of a calibration is only valid at the moment of its accomplishment. In order to estimate the behaviour of the calibrated instrument in the future, one has to revert to experiences from the past. Thus, the uncertainty of measurements grows with time, depending on the gathered experiences.

Test procedures are used to determine if an instrument fulfills stipulated requirements like e.g. error margins under rated operation conditions. Usually, possible values for relevant influence factors are predefined in a reasonable range by the manufacturer of the instrument under test [8].

Test procedures play an important role in legal metrology where they facilitate trust in the accuracy, stability and dependability of measurements. Standards and normative documents stipulate maximum permissible errors which may not be exceeded.

Aiming for realistic calibration and test procedures for AWIs close to day-to-day routine measurements is a major challenge due to the plethora of varying instrument types and applications, most of which necessitate specific routines. Already existing testing and calibration procedures which could be helpful in developing these new routines are briefly presented in the following.

5. TEST PROCEDURES

There are a number of OIML recommendations which determine test procedures for different kinds of AWIs [9-14], see Table 1. Besides test procedures, also metrological and technical requirements are specified by these recommendations. They are intended to provide standardised requirements and testing procedures in order to evaluate the metrological and technical characteristics of AWIs in a uniform and traceable way.

Usually, dynamic effects are not examined explicitly. Instead, the tests are carried out under “worst-case-conditions” which are to be expected considering the design and parameter settings of the test specimen.

Table 1: Construction forms of AWIs and corresponding OIML recommendations

Designs of AWI	OIML recommendation
Continuous totalizing automatic weighing instruments (belt weighers)	OIML R50 [9]
Automatic catchweighing instruments	OIML R51 [10]
Automatic gravimetric filling instruments	OIML R61 [11]
Automatic rail-weighbridges	OIML R106 [12]
Discontinuous totalizing automatic weighing instruments (totalizing hopper weighers)	OIML R107 [13]
Automatic instruments for weighing road vehicles in motion and measuring axle loads	OIML R134 [14]

The recommendations establish technical requirements considering characteristics like suitability for use, security of operation, indication of weighing results, software in use, and security measures. Moreover, specifications are defined for functions like zero-setting, tare, data storage and printing. For AWIs equipped with electronics, additional requirements are stipulated concerning voltage variations, span stability, warm-up times as well as electromagnetic disturbances due to surge, burst or electromagnetic radiation.

Furthermore, the recommendations define maximum permissible errors (mpe) due to external factors of influence like temperature, humidity, air pressure, tilting and eccentric loading. Typically, OIML recommendations for AWIs divide the instruments into primary categories and accuracy classes according to their use. Maximum permissible errors for influence factors are then specified based on this classification, see Table 2 for an example.

Table 2: Accuracy classes and maximum permissible errors for automatic catchweighers (OIML R51, category Y)

Load, *m*, expressed in verification scale intervals, *e*				Maximum permissible error for category Y instruments	
Y(I)	Y(II)	Y(a)	Y(b)	Initial veri-fication	In-service inspection
0≤*m*≤50000	0≤*m*≤5000	0≤*m*≤500	0≤*m*≤50	±1*e*	±1,5*e*
50000≤*m*≤200000	5000≤*m*≤20000	500≤*m*≤2000	50≤*m*≤200	±1,5*e*	±2,5*e*
200000≤*m*	20000≤*m*≤100000	2000≤*m*≤10000	200≤*m*≤1000	±2*e*	±3,5*e*

Although a statement of measurement uncertainties based on the requirements, test procedures and maximum permissible errors defined in OIML recommendations is not immediately possible [15-17], the test procedures described therein can serve as the basis for dynamic calibration methods for different groups of AWIs. The calibration guides which are to be compiled in the course of the European research project should consider influence factors as well as technical and metrological requirements already specified in existing OIML recommendations.

6. STATIC CALIBRATION PROCEDURES

Non-automatic weighing instruments are routinely calibrated by accredited calibration laboratories according to the EURAMET Calibration Guide cg-18 "Guidelines on the calibration of non-automatic weighing instruments" [3]. This guide provides harmonized and validated measurement methods and calibration procedures. It is based on OIML recommendation R76 "Non-automatic weighing instruments" [18] and adopts its well-defined requirements and test procedures, e.g. concerning accuracy, repeatability and eccentricity. Contrary to OIML R76 requirements, calibration is carried out under fixed environmental conditions and without taking electromagnetic radiation into account.

While OIML R76 does neither provide error models for the weighing process, nor uncertainty budgets for the calibration or the weighing results, the calibration guide cg-18 deals with these questions. The uncertainty of measurements depends significantly on the properties of the calibrated instrument itself, like linearity, hysteresis and repeatability. Furthermore, effects due to the resolution of the indication, warm-up behavior or eccentric loading need to be taken into account.

In addition, the uncertainty of measurements is influenced by the equipment used for calibration, e.g. by the weights and how these are placed on the weighing platform [19, 20]. Further uncertainty contributions originate from buoyancy effects of the calibration weights and from convection effects due to temperature differences between the environment, the weight and the weighing instrument.

Even though dynamic measurement processes are beyond the scope of the calibration guide cg-18, many considerations of static calibrations can be usefully transformed to the calibration procedures and uncertainty estimations for AWIs in dynamic mode which are to be developed within the European research project.

7. DYNAMIC CALIBRATION PROCEDURES

Because force measurements play a major role in industrial processes, not only static but also dynamic calibration procedures for force transducers have been developed [21-13]. These could also be of relevance for dynamic weighing technologies, since force transducers and load cells use similar measurement principles and technologies.

One possibility to calibrate force transducers is based on sinusoidal excitation of the transducer and an additional load mass by an electrodynamic shaker system under defined environmental conditions [24]. The acting dynamic force can be determined according to Newton's law as the product of mass times acceleration. The acceleration is measured on the surface of the load mass by means of a laser interferometer. An overview of the measuring setup can be seen in Figure 4.

Experiments and analytical models show that the sensitivity of the force transducer decreases by a few percent with increasing frequency of up to 2 kHz [24, 25]. Using the described calibration procedures, this sensitivity may be determined with uncertainties between 0.4% and 1.0% for frequencies below 1 kHz. The uncertainties at higher frequencies are between 1% and 2% [26]. The results also show that there is a significant influence of the coupling between the load mass and the force transducer [24]. Other influence factors, e.g. rocking modes due to imperfect rigidity of the transducer or unbalances in the structure, may occur at certain frequencies and can result in major measurement errors [27].

The sinusoidal dynamic calibration procedures for force transducers cannot be applied directly to automatic weighing instruments in dynamic operation where impulse-shaped loads predominantly occur. Nevertheless, the observed influence factors should be transferable.

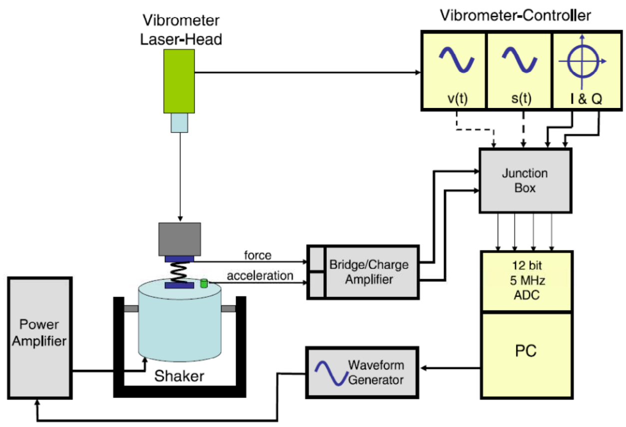

Fig. 4: Schematic calibration setup consisting of a shaker system with mounted force transducer, a vibrometer system and the electrical equipment for signal processing [24].

8. MODELLING AND UNCERTAINTY OF DYNAMIC WEIGHING PROCESSES

Various theoretical models for the dynamic behaviour of weighing instruments have been proposed on the basis of experimental investigations [28, 29]. Most of these models are developed in order to study the dynamic processes and to optimize them, e.g. regarding speed [30, 31]. Due to the large variety of different applications, construction forms, and measurement principles, no general conclusions can be drawn.

Considerations regarding measurement uncertainty for weighing road vehicles in motion exist in countries like Poland and the Czech Republic which use automatic instruments for weighing road vehicles in motion for the purpose of law enforcement. Partly, exhaustive studies have been performed allowing statistical analysis [5]. These analyses are one step on the route to rigid uncertainty budgets. Further steps are models for weighing-in-motion [32, 33] or the examination of specific influence factors [34-36].

The models and considerations described above will be helpful for the determination of uncertainties of AWIs which is aimed for in the European research project.

9. CONCLUSION AND OUTLOOK

There is an increasing demand for calibration procedures for AWIs. We tried to give an overview of existing experiences considering test procedures and calibration methods. Although this knowledge is a good starting point, much work remains to be done.

We are confident that combining the proficiency and comprehensive experiences of the project partners will lead to substantial improvements concerning issues like influence factors, dynamic effects and uncertainty budgets based on existing tests and calibration procedures for automatic and also non-automatic weighing instruments.

REFERENCES

[1] Prodcom Database http://ec.europa.eu/eurostat/en/web/prodcom

[2] "Directive 2004/22/EC of the European Parliament and of the council of 31 March 2004 on measuring instruments", *Official Journal of the European Union,* vol. L 135, pp. 1-80, 2004.

[3] EURAMET cg-18, "Guidelines on the Calibration of Non-Automatic Weighing Instruments", vol. 3.0, 2011.

[4] R. Nater, A. Reichmuth, R Schwartz, et al., *Wägelexikon: Leitfaden wägetechnischer Begriffe*, Springer-Verlag, Berlin, 2008.

[5] B. Jacob, E. O'Brien, S. Jehaes, *COST 323, "Weigh-in-motion of Road Vehicles", Final Report*, Laboratoire Central des Ponts et Chausseess, Paris, 2002.

[6] R. Schwartz, "Automatic Weighing – Principles, Applications & Developments", *XVI IMEKO World Congress*, Vienna, Austria, 2000.

[7] *Evaluation of measurement data – Guide to the expression of uncertainty in measurement,* Joint Committee for Guides in Metrology, 2008.

[8] Document D11, *General requirements for measuring instruments – Environmental conditions,* OIML, Paris, 2013.

[9] Recommendation R50, *Continuous totalizing automatic weighing instruments (belt weighers),* OIML, Paris, 2014.

[10] Recommendation R51, *Automatic catchweighing instruments,* OIML, Paris, 2006.

[11] Recommendation R61, *Automatic gravimetric filling instruments,* OIML, Paris, 2004.

[12] Recommendation R106, *Automatic rail-weighbridges,* OIML, Paris, 2001.

[13] Recommendation R107, *Discontinuous totalizing automatic weighing instruments (totalizing hopper weighers),* OIML, Paris, 2007.

[14] Recommendation R134, *Automatic instruments for weighing road vehicles in motion and measuring axle loads,* OIML, Paris, 2006.

[15] H. Morinaka, "Uncertainty in type approval and verification", *OIML Bulletin,* vol. XLVII, nº. 1, pp. 5-11, 2006.

[16] O. Pellegrino, C. Pires, A. Cruz, "Speed measurement uncertainty in metrogical [*sic*] verifications at IPQ", *XIX IMEKO World Congress,* pp. 1461-1462, Lisbon, Portugal, 2009.

[17] H. Källgren, K. Lindløv, L. Pendrill, „Uncertainty in conformity assessment in legal metrology (related to MID)", *OIML Bulletin,* vol. XLVII, nº. 3, pp. 15-21, 2006.

[18] Recommendation R76, *Non-automatic weighing instruments,* OIML, Paris, 2006.

[19] A. Vâlcu, "Calibration of nonautomatic weighing instrument", *XVIII IMEKO World Congress,* Rio de Janeiro, Brazil, 2006.

[20] L. O. Becerra, E. González, F. Pezet et al., "Comparison of methods for the weighing test in calibration of high capacity non-automatic weighing instruments", *XVIII IMEKO World Congress,* Rio de Janeiro, Brazil, 2006.

[21] R. Kumme, B. Glöckner, C. Schlegel, „A new facility for continuous and dynamic force calibration with forces up to 100 kN", *IMEKO 2010 TC3, TC5 and TC22 Conference,* pp. 13-16, Pattaya, Thailand, 2010.

[22] Y. Fujii, "Dynamic Calibration Methods for Force Transducers", *XVIII IMEKO World Congress,* Rio de Janeiro, Brazil, 2006.

[23] M. Kobusch, S. Eichstädt, L. Klaus et al., „Investigations for the model-based dynamic calibration of force transducers by using shock forces", IMEKO 22nd TC3, 12th TC5 and 3rd TC22 International Conference, Cape Town, South Africa.

[24] C. Schlegel, G. Kieckenap, B. Glöckner et al., „Traceable periodic force calibration", *Metrologia*, vol. 49, pp. 224-235, 2012.

[25] R. Kumme, "A new calibration facility for dynamic forces up to 10 kN", *XVII IMEKO World Congress,* pp. 305-308, Dubrovnik, Croatia, 2003.

[26] C. Schlegel, G. Kieckenap, B. Glöckner et al., „Dynamic Calibration of Force Transducers Using Sinusoidal Excitations", *Sensordevices 2011: The Second International Conference on Sensor Device Technologies and Application,* pp. 8-13, Nice, France, 2011.

[27] C. Schlegel, G. Kieckenap, R. Kumme, "Uncertainty Contributions in Sinusoidal Force Measurement", *IMEKO 22nd TC3, 12th TC5 and 3rd TC22 International Conference,* Cape Town, 2014

[28] Y. Yamakawa, T. Yamazaki, J. Tamura et al., "Dynamic behaviors of a checkweigher with electromagnetic force

compensation", *XIX IMEKO World Congress*, pp. 208-211, Lisbon, Portugal, 2009.

[29] Y. Yamakawa, T. Yamazaki, "Mathematical model of checkweigher with electromagnetic force compensation", *XX IMEKO World Congress*, Busan, Korea, 2011.

[30] K. Fukuda, K. Yoshida, T. Kinugasa et al., "A new weighing method for checkweighers by using signal processing", *XIX IMEKO World Congress*, pp. 373-378, Lisbon, Portugal, 2009.

[31] T. J. Esward, C. Elster, J. P. Hessling, „Analysis of dynamic measurements: New challenges require new solutions", *XIX IMEKO World Congress*, pp. 2370-2310, Lisbon, Portugal, 2009.

[32] E. Kulderknup, J. Riim, T. Levandi, "Uncertainty of road traffic safety measurements", *XIX IMEKO World Congress*, pp. 1439-1442, Lisbon, Portugal, 2009.

[33] K. Fukada, K. Yoshida, T. Kinugasa et al., "Axle weighing for in-motion vehicles using simple FIR filters", *XX IMEKO World Congress*, Busan, Korea, 2011.

[34] L. B. Faruolo, F. A. d. N. C. Pinto, „Analysis of weigh-in-motion tank vehicles transporting liquid cargo on highways", *OIML Bulletin*, vol. LVI, nº. 1, pp. 8-19, 2015.

[35] D. M. Senyanskiy, "Problem of increasing the accuracy of railway carriages weighing in motion", *XVII IMEKO World Congress*, pp. 374-377, Dubrovnik, Croatia, 2003.

[36] K. Tada, S. Hayashida, T. Uchimaru et al., "Dynamic force sensing – Dynamic axis scale with high speed and heavy running vehicle", *XX IMEKO World Congress*, Busan, Korea, 2011.