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METROLOGICAL EQUIPMENT FOR VERIFICATION AND CALIBRATION OF NON-AUTOMATIC WEIGHING INSTRUMENTS – AXLE AND CRANE WEIGHTING INSTRUMENT

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Abstract

The paper deals with the design of equipment for verification and calibration of axle and crane weighing instruments. In its introduction, it discusses the basic concepts of axle and crane weighing instruments, their calibration, and verification. The paper briefly describes the original technical design solution used in the calibration and verification of these weighing instruments. Subsequently, the article describes the legislative, technical and functional requirements for metrological equipment being developed. The paper presents two design solutions for handling calibration weights. In both solutions, the construction and individual functional parts of the equipment are described. Both of these solutions were designed and tested in practical measurements in the Laboratory for Testing of Weighing Instruments of the Slovak Legal Metrology n.o. Finally, the paper presents the results of the development of a new measuring system at the University of Žilina.

Keywords: metrology, calibration, verification, weights, design.

1. Introduction

The paper describes the construction design of metrological equipment used for the realization of selected metrological tests on axle and crane weighing instruments. Specifically, it is the calibration and verification of these weighing instruments. The weighing instrument calibration is a set of operations under defined conditions that determine the relationship between the value indicated by the meter and the value realized by the reference standard. Weighing instrument verification is used to verify the accuracy of the weighing instrument that had already been calibrated in the past [1]. The equipment is designed for crane and axle weighing instruments with a weighing capacity of up to 10 tons.

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Axle and crane weighing instruments belong to the group of non-automatic weighing instruments. This group of weighing instruments includes weighing instruments that require operator intervention during the weighing process, especially as regards the loading and unloading of an item to be weighed on the load carrier. The load carrier is the part of the weighing instrument primarily intended for the application of the load. The basic characteristic of the axle weighing instrument is the extremely small area of the load carrier, with a maximum weighing capacity of up to 10 tonnes [2]. The hanging weighing instrument is characterized by the axial load.

Testing of the weighing instrument over the entire measuring range is a precondition for the correct interpretation of metrological control results, *i.e.* calibration followed by meter verification [3]. However, the calibration of axle and crane weighing instruments close to the maximum weighing capacity is a complex task in terms of time, complexity, technical support and safety. The metrological control of axle and crane weighing instruments is regulated by normative and legislative requirements in compliance with the Slovak Technical Norm STN EN 45501 Metrological aspects of non-automatic weighing instruments. This standard specifies the requirements to use the method by direct comparison with standard weights or a precisely defined proportion of weights against the maximum value of the weighing range. One of the aims of the paper is to present the results of research and development in the construction of a new measuring device operating in an automated mode as a result of research conducted at the Slovak Legal Metrology and the University of Žilina.

2. Original state of testing equipment

The original solution used to calibrate the axle weighing instruments applied the prescribed method in practice. The basis of the solution was a rigid metal plate of dimensions 1000 × 1000 mm, a set of 20 pieces of weights (for the range up to 10 tons) with a nominal mass (weight value) of 500 kg with its dimensions of 450 × 450 × 450 mm. An electric hoist was used to handle the weights. The area on which the axle weighing instruments were placed complied with all the specified error requirements for flatness and slope. The metal plate was placed on a weighing instrument carrier in order to increase its loading area. The weights were gradually placed on a weighing plate using the electric hoist. The use of the equipment was associated with the requirement for correct placement of the centre of gravity of the plate in the centre of the weighing instrument carrier, as well as precision in locating or subsequent stacking of the weights on the plate. The technical solution made it possible to load 20 pieces of weights only at the theoretical level. The main drawbacks of this equipment were the limited scope of testing, the demanding process of eliminating the impact of eccentric loads such as weights sliding down, the operator being present at the work area and loss of balance during manipulation with hanging heavyweight blocks.

In the case of calibration of hanging weighing instruments, a technical solution was used consisting of a structure with a lifting eye bolt and connecting accessories for the suspension of a set of standard weights and handling equipment. The weights were gradually joined by hand with connecting accessories to a structure that was lifted with a handling technique [4]. The main drawbacks of the equipment were problems with load setting for reading the indicated value, the difficulty in clamping standard weights and safety risks during manipulation with the weights.

3. New equipment requirements

The proposed metrological equipment meets the requirements of the Slovak Technical Norm STN EN 4551:2015. The essential requirement is the possibility of placing verification standards. These are basically standard blocks. They meet the metrological requirements of the OIML R111-1 International Organization of Legal Metrology International Recommendations and their error is not greater than one-third of the permissible error of the weighing instrument for the applied load.

When performing metrological tests, the correct load must be applied in accordance with the performance test requirements. The first of the functional tests is the repeatability test, in which the ability of the weighing instrument to produce identical results must be demonstrated when the same weight is loaded several times practically in the same way on the load carrier under sufficiently constant test conditions [5]. The second of the functional tests is the accuracy test and determination of indication errors. In this test, it should be possible to calculate the indication errors as a difference between the weight indication and the value corresponding to the weight or the conventionally true mass (weight value) realized by the measuring equipment.

The basic technical requirements are the weighing capacity of up to 10 tons, the possibility of gradual adding of the load at individual test points. and, conversely, the possibility of gradual load removal at the same points as at placing the load. A further requirement is to minimize the need to translate (load and unload) the standard weights when changing the weighing capacity or the type of the weighing instrument (axle or crane instruments). An important requirement is also to eliminate the safety risk during the process of calibration and verification, but also during manipulation with the weight blocks. The area around the equipment should be free of obstacles so that the operator can read the readings on the tested weighing instrument without any problems. The equipment should be compact, with no significant modification to the type of the weighing instrument to avoid prolonged downtimes between individual tests. Functionally, the equipment must be able to operate in both manual as well as semi-automatic modes. The equipment must be installable in the interior of the laboratory of the Slovak Legal Metrology n.o. which also includes an electric overhead crane with a load capacity of 1,000 kg [6]. The innovativeness of the device lies in the following possibilities:

– Technician does not come into contact with weights during the measurement,
– Weights are stored below ground level which increases safety at work,
– Weight change during verification is automatic and precisely defined,
– Time required for metrological performance is reduced,
– Processing measurement data is automated.

4. Construction design

One of the basic conditions, namely that of gradual load application at individual points, and conversely, the possibility of load removal at the same points as during load application became the basis for the design solution of the presented metrological equipment construction. The base of the equipment is a hanging cage (1). The hanging cage includes four plates placed on the sides with milled oval grooves (2). The length of each groove increases from top to bottom at regular intervals. The upper part of the side walls of the hanging cage (3), which can be demounted, is connected by a connecting beam (4). Thanks to the demountable upper part of the cage, weights can be placed in the centre of the cage (5). Up to six baskets with standard weights can be stacked in the middle of the hanging cage. The hanging cage and the baskets with weights have a known mass (weight value) and represent the calibration load.

The whole set of the hanging cage with baskets is located in a pit of 2,500 mm length, 2,000 mm width and 2,200 mm depth. Thus, the part of the equipment that generates the calibration load is below the floor level of the laboratory, which increases the safety of the equipment. In the basic position, the hanging cage and baskets are laid on the pit floor.

The principle of the equipment lies in gradual lifting of the hanging cage, which, thanks to the pins on the baskets stored in its milled oval grooves, gradually binds the individual baskets with weights. This ensures gradual load application at the necessary measuring points and gradual load removal at the same points as the frame moves backwards (Fig. 1).

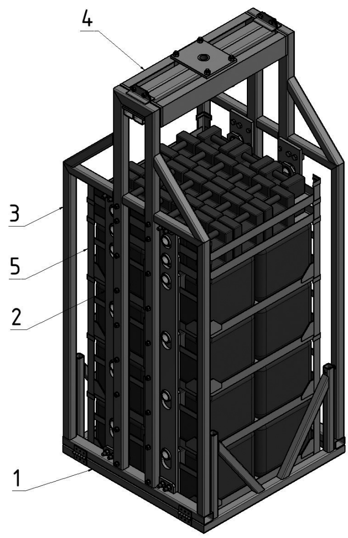

Fig. 1. Hanging frame with baskets with standard weights.

4.1. Lifting of the hanging cage using hydraulics

The first version of the equipment worked with the cage lift using a hydraulic cylinder. In that case, a single-acting cylinder (6) with a piston diameter of 130 mm and a piston rod diameter of 110 mm was used in the metrological tests of the axle weighing instruments. This was screwed under the upper connecting cage beam (4). The pit in which the basket cage was placed was covered with a transverse plate (7) on which the test weights were placed. The hydraulic cylinder piston pushed the load carrier (8), lifted the hanging cage (1) and, with an increasing stroke, gradually picked up all baskets with standard weights (5).

In the case of testing the crane weighing instruments, a pulling hydraulic cylinder (10) securing the lifting of the hanging cage (1) was suspended on the measuring equipment portal (9). The tested crane weighing instrument (11) was suspended on the cylinder piston rod and its hook was attached to the connecting beam of the hanging cage (Fig. 2).

Initial functionality tests were performed on this version of the equipment. The hydraulic circuit of each cylinder was driven by a hand pump. During the testing, the correct application

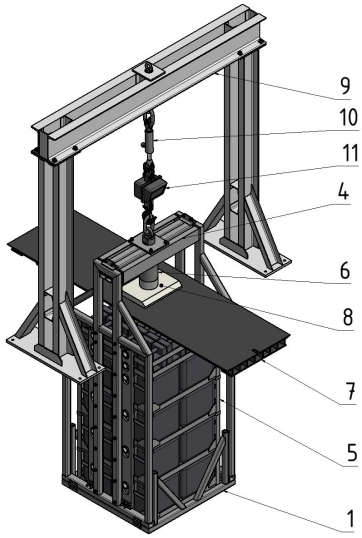

Fig. 2. Equipment with the hydraulic lifting of the hanging frame with baskets.

and removal of the load on the tested weighing instrument were verified. The overall functionality of the individual components of the equipment was also verified.

However, the hydraulic cylinder lifting the cage when testing the axle weighing instruments proved to be a major design deficiency, as the increase in the volume of the fluid in the cylinder negatively influenced the measurement results. At the maximum cylinder stroke, the mass gain was up to 1,711 kg.

4.2. Lifting of the hanging cage by means of worm gearboxes

The innovation of the equipment consisted of the realization of lifting (or lowering of baskets and the cage) by means of an electric motor and worm gearboxes. An electric motor (12) was placed at the bottom of the pit; driving four worm gearboxes (15) via cardan shafts (13) and the auxiliary technology gearbox (14). The output shaft of the worm gear has a trapezoidal thread with a nut (16) thereon. The worm gear nuts are bolted to the support plate (17) on which the hanging cage (1) with baskets (5) is placed (Fig. 3).

The equipment works in the opposite way compared to the first version. In this case, the hanging frame, which gradually takes up the baskets, does not lift, but on the contrary, the hanging frame, also from the baskets placed on the carrier plate, is lowered from the maximum vertical position to the minimum. A load bar (18) is screwed to the connecting beam, the end of which acts directly on the load carrier of the axle weighing instrument being under test (19).

In the case of the crane weighing instrument being tested, the test crane weighing instrument (21) hangs on the adjusting suspension item (20) that is attached to the eye of the load-bearing portal (9) and the hanging cage with baskets [7] is attached to the hook of the weighing instrument. The support plate carrying the hanging cage with baskets is lowered slowly, thus creating an increasing load on the test weighing instrument. After testing all the measuring positions, the support plate returns to its maximum vertical position and relieves the test weighing instrument.

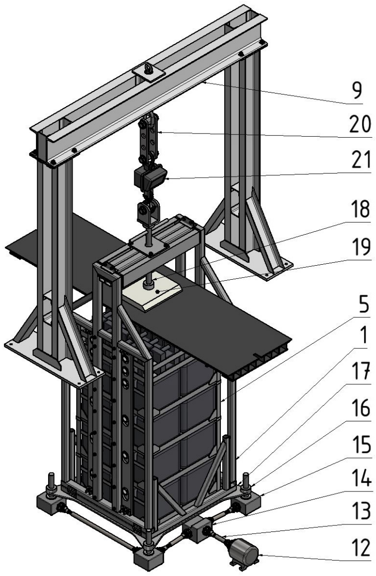

Fig. 3. Equipment with the mechanical lifting of the hanging frame with baskets.

5. Measurement methodology

The functional test of the axle weighing instrument begins when the tested measuring equipment is being placed at a defined position on a cross plate above which there is a cage connecting beam with an adjustable strut bar. In the case of a hanging weighing instrument, it hangs on the lifting eye bolt which can be used to define the distance between the portal located in the stroke axis of the connecting beam and the towing bar to which the hanging weighing instrument is connected by a hinge cage pin. This adjustable bar defines the free space between the weighing instrument carrier and the cage cross. If this operation is accomplished, the weighing instrument test itself can start (Fig. 4).

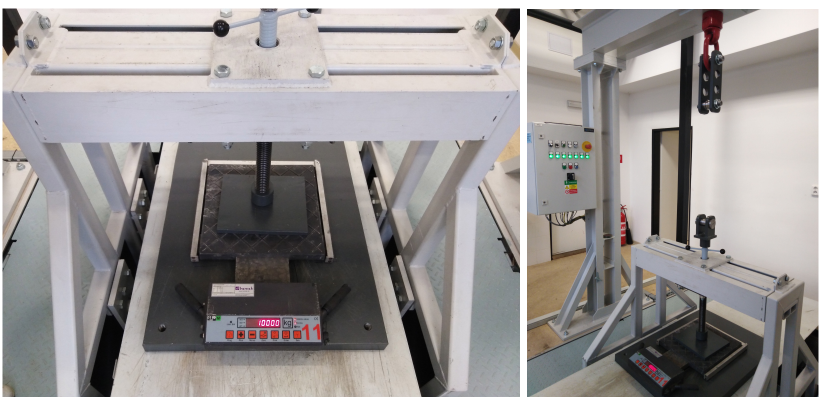

Fig. 4. Test of the axle weighing instrument in the Laboratory for testing of weighing instruments of Slovak Legal Metrology.

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The first part of the test is the repeatability test, which consists of three repetitive loads of approximately 0.8 of the maximum of the weighing instrument, followed by relief and relaxation phase. The second part is a test to determine the error of the weighing instrument indication that consists of the gradual introduction of the load (uploading) and unloading (load removal), *i.e.* individual baskets with a weight. Table 1 describes the individual measuring positions and their nominal weights, the standard load uncertainty, the composition of the individual measuring positions, the pieces and the type of weights per respective measuring position.

Table 1. Measuring Positions.

Measuring Position	**Nominal Weight of the Position (kg)**	**Conventional Load Weight (kg)**	**Standard Load Uncertainty $u_{\delta mc}$ (kg)**	**U (kg)**	**Load Composition**		
					Construction	**Weights**	**Adjustment Weights (Mass and Composition)**
Start Position	0	0	–	–	–		
K1	600	600	0.025	0.06	Cage	–	–
K2	900	1,500	0.048	0.15	Cage + Basket No. 1	200 kg: 4 pcs 20 kg: 1 pc	15.6 kg; 10 kg – 1 pc, 5 kg – 1 pc, adjustment material
K3	500	2,000	0.068	0.2	Cage + Baskets No. 1, 2	20 kg: 21 pcs	15.1 kg; 10 kg – 1 ks, adjustment material
K4	1,700	3,700	0.09	0.37	Cage + Baskets No. 1, 2, 3	200 kg: 8 pcs	2.77 kg; adjustment material
K5	2,100	5,800	0.113	0.58	Cage + Baskets No. 1, 2, 3, 4	500 kg: 4 pcs	3.14 kg; strut bars 2 pcs
K6	2,100	7,900	0.136	0.79	Cage + Baskets No. 1, 2, 3, 4, 5	500 kg: 4 pcs	3.17 kg; strut bars 2 pcs
K7	2,100	10,000	0.159	1	Cage + Baskets No. 1, 2, 3, 4, 5, 6	500 kg: 4 pcs	3.12 kg; strut bars 2 pcs

6. Evaluation of results

The evaluation of the performed measurements consists of calculation of the result values, comparison of the findings with the prescribed data according to the evaluation criteria, evaluation of the measurement uncertainty, and evaluation of the measurement results [8]. For the calculation of the conventional (reference) mass value of the weights, the following model applies:

$$m_{ref} = m_N + \delta m_C + \delta m_B + \delta m_D\,, \tag{1}$$

where:
m_n is the nominal mass value of the weights,
δm_C is the correction to m_n with which we obtain the conventional true mass value of the δm_C weight (as stated in the calibration certificate),

δm_B is the air buoyancy correction, which is dependent on the density of the calibration weight ρ and the assumed range of air density ρa,

δm_D is the correction for a possible drift of the standard weight since the most recent calibration.

The calculation of the resulting values, their comparison with the evaluation criteria and the evaluation of measurement uncertainties should preferably be performed electronically by means of relevant software.

6.1. Repeatability test

During the repeatability test, the maximum difference ΔP of the axle or hanging weighing instrument indication will be determined according to these formulae:

During the repeatability test, the maximum difference ΔP in the indication of axle or suspended weighing instrument shall be determined in accordance with STN EN 45501:2015 as follows:

$$P = I + \frac{e}{2} - \Delta L, \tag{2}$$

$$E = P - L, \tag{3}$$

where:

E is the weight indication error,

$e/2$ is half of the verification scale interval,

P is the indication before rounding,

I is the indication,

ΔL is the additional load,

L is the load.

From the P, the difference between the maximum and the minimum shall be determined:

$$\Delta P = P_{\max} - P_{\min}, \tag{4}$$

where:

$P_{\max}$ is the maximum actual indication before rounding,

$P_{\min}$ is the minimum actual indication before rounding,

or

$$\Delta E = E_{\max} - E_{\min}, \tag{5}$$

where:

$E_{\max}$ is the maximum error before rounding,

$E_{\min}$ is the minimum error before rounding.

6.2. Weighing test

Test loads are applied from zero up to the maximum, and similarly, test loads are removed back to zero. When evaluating the accuracy of the data provided by the weighing instrument, the weight indication error E at the given load is calculated. For each test point on the scale weight indication error E – is determined according to the formulae:

$$E = P - L = I + \frac{e}{2} - \Delta L - L, \tag{6}$$

$$E_C = E - E_0, \tag{7}$$

where:

E_0 is the error calculated at zero or at a load close to zero,

E_C is the corrected error prior to rounding.

6.3. Evaluation of standard uncertainty

The basic formula for the calibration is:

$$E = I - m_{ref}. \tag{8}$$

Validation software developed by the Slovak Legal Metrology n.o. is used to evaluate the measurement including uncertainty of measurement.

From the results of one repeatability test we can determine the standard deviation and calculate standard uncertainty. This uncertainty of repeatability can be considered as representative for the whole range of the instrument. The standard uncertainty (u_A) – is calculated on the basis of three repeated measurements ($n = 3$) according to STN EN 45501, point A.4.10 performed at the three test points according to the formula:

$$u_A = \sqrt{\frac{1}{n \cdot (n-1)} \cdot \sum_{i=1}^{n} \left(I_i - \overline{I}\right)^2}, \tag{9}$$

where:
I_i is the mass value indicated by the weighing instrument (obtained when the verification scale interval is changed over if the changeover point method is applied),
I is the arithmetic mean of the mass value indicated by the weighing instrument or the calculated mass value at the changeover point if the changeover point method is applied when the weights of the same mass are used repeatedly.

6.4. Evaluation of combined standard uncertainty

From the standard uncertainties the combined standard uncertainty u_C [9] is calculated according to the formula:

$$u_C = \sqrt{u_A^2 + u_{\delta mc}^2 + u_r^2 + u_{r0}^2 + u_{\delta mD}^2}, \tag{10}$$

where:
$u_{\delta mc}$ is the uncertainty of calibration of standard weights (reference mass) from the calibration certificate $u_{\delta mc} = U/k$, normal distribution of the load assumed. If the test load consists of more than one standard weight, the standard uncertainties shall be calculated arithmetically. The construction design of the load device is part of the load and is calibrated as a special weight,
u_r is the uncertainty due to the effect of the weighing instrument resolution under load $i.e.$ verification scale interval d, uniform distribution of the load assumed,
u_{r0} is the uncertainty due to zero resolution, $i.e.$ the verification scale interval at *d0* zero (or close to zero, $e.g.$ $10e$), uniform distribution of the load assumed,
$u_{\delta mD}$ is the uncertainty due to the effect of D drift of the standard weight since the most recent calibration, we assume a uniform distribution and $u_{\delta mD} = D/\sqrt{3}$.

7. Conclusions

The proposed metrological equipment meets all the design and metrological requirements described in the introductory part of this paper. The equipment partially automated the process of verification and calibration of crane and axle weighing instruments, which has increased the efficiency of testing and thus shortened the time needed for calibration or verification of one weighing instrument up to four times. The equipment has also increased the accuracy of calibration and verification of axle and crane weighing instruments. The device increased the safety of the operator while performing metrological tests. The described metrological equipment can be applied in calibration and testing laboratories of manufacturers, service organizations, authorized bodies for verification of measuring instruments mentioned above. The equipment can also be used to test force sensors. The equipment is currently operated by Slovak Legal Metrology n.o. in the Laboratory for Testing of Weighing Instruments at their Bratislava branch. The functional principle of the equipment has been registered as Utility Model No. PUV SK 282-2017. The results of research and development were created with support of APVV-15-0164 and APVV-18-0066 projects.

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