RADWAG BALANCES AND SCALES
ADVANCED WEIGHING TECHNOLOGIES

Mass Measurement Automation

FOUNDATIONS OF METROLOGY, WEIGHING SYSTEMS AND AUTOMATIC WEIGHING MACHINES

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RADWAG Balances and Scales
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1. Introduction

Scales origin goes back to ancient times, the instrument has been related to trade and preparation of goods for market from the very beginning. The first scale was designed in ancient Egypt about 5 – 7 thousand years ago. It was a beam balance consisting of a lever with two equal arms, featuring weighing pans suspended on the lever ends, the balance was either supported by a stand or hang on a rope.
Granite rocks, carved to remind animal's torso, served as weights. The scales were used in trade and in agriculture, right next to measuring dishes they served as a fundamental tool for measurement and calculation purposes.
The next step when it comes to scales development was so called steelyard balance invented by Romans. The steelyard was nothing else but a straight graduated beam to which the weighed load was hung close to one of its ends, the load mass readout was carried out using counterweight which indicated particular value while being moved along the other end of the beam. The steelyard and beam balance likewise operated on the basis of balance/equilibrium. Use of mass standards was not required.
Over the course of time, the scales was being subjected to modernization as far as functionality is concerned, however the principle of operation remained unchanged. The device either featured two weighing pans and was equipped with mass standards or it operated like the steelyard balance does. At the turn of XVI and XVII century spring scale was invented, the indication readout required no additional operations to be performed by the user. Upon attaching the weighed object to a hook the spring was extended providing immediate readout with use of scale markings.
Industrial revolution that began in XVIII century in England and Scotland, i.e. turning from manufacture to automation, brought in advancement as far as dedicated industrial equipment is concerned. It was the starting point for development of autonomously operating devices, by means of which repeatable manufacturing processes were carried with no need of assistance of the operator. The said period is also a rapid evolution of mechanical scales, which evolution reached its climax at the turn of XIX and XX century. At that time numerous new designs were developed, the scales started to be manufactured in series. However because of design and technological limitations the scales still remained simple measuring devices automation of which was rather poor if not impossible.
In the mid XX century both computerization and automation flourished in production, with this scales so far perceived as simple weighing instruments started to be looked at from a new perspective. Users began to demand numerous extra process, control and communication functions enabling use, processing and automatic transfer of the basic scale-generated data, i.e. weight value. Clear division of industrial weighing equipment with regard to the intended use took place. As a result, the weighing instruments are designed, programmed and equipped with dedicated function modules depending on the usage requirements. Particular scale design and use is determined by the fact to which product category, specified by currently valid regulations, the scale is assigned. Control procedures for a given scale type depend on the design and use, i.e. on the category.

This publication aims to present new possibilities of technologically advanced weighing instruments, inform on a technological development state when it comes to industrial metrology, supply vast range of applications and provide valid regulations to which metrological equipment is subjected, all the above with respect to non-automatic scales as well as to automatic ones.

2. Foundations of Metrology

Each user of a weighing instrument shall be aware of the fact that control over the equipment is extremely important, with it, correct functioning is guaranteed. The control concerns both technical condition of a particular device and fulfilment of user- or law-specified requirements, that are obligatory for a given country. This shows how important it is to be familiar with law regulations and valid standards.

Each user of a weighing instrument knows that in order to ensure trustworthy indications it is necessary to be confident about equipment reliability. Until recently it was considered that a device is reliable when it meets requirements of particular quality standards, whereas no detailed analysis was given to the very requirements. Awareness of weighing equipment users has increased and these days they see control over the measuring equipment, proving whether regulations are met or not, as an essential need.

2.1. Basic Metrological Terms

Basic, fundamental metrological terms have been defined and published in an *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms* (PKN-ISO.IEC Guide 99) and they refer to notions regarding measuring units, measurement, measuring devices, measuring devices characteristics and mass standards. The dictionary provides 144 terms valid for metrology. Another significant document supplying the readers with definitions is an *International Vocabulary of Terms in Legal Metrology*, here one can find 44 notions that are valid for legal metrology. Some of the most elementary definitions, strictly referred to measurement in industry, have been presented below:

Error of indication
Measured quantity value minus a reference quantity value.

Verification Mark
Mark applied to a measuring instrument in a conspicuous manner certifying that the verification of the measuring instrument was carried out and compliance with statutory requirements was confirmed – legal metrology.

Certification
Process in the course of which technical parameters of weighing instruments are tested, during the tests, indications are checked and compared to threshold values specified by European Standard, PN-EN 45501, or Directive, 2004/22/WE (depending on the used measuring instrument). The tests are considered to be correct when all the results are positive, i.e. when indications errors are not greater than maximum permissible errors (MPE). With regard to this relation the particular device (series) is issued a certificate (type approval).

Sampling Interval
Time interval within which balance indication is analysed. Measurement result is provided by a converter which tests (samples) the measuring signal constantly, the signal is next processed by filtering systems.

Declaration of Conformity
Declaration of conformity is a document issued by the manufacturer, stating that weighing equipment to which it is referred adheres to approved type and it does meet requirements of all applicable directives.

Actual Scale Interval, d
Value, expressed in units of mass, of the difference between the values corresponding to two consecutive scale marks, for analog indication, or of the difference between two consecutive indicated values, for digital indication. Electronic scales usually feature the following scale intervals:
1,2,3,4,5,6,7,8,9,0
0,2,4,6,8,
0,5.

Actual scale interval for verified balances is regulated with respective provisions. For non-verified balances the scale interval is specified by the manufacturer. It happens the most frequently that each balance features ONE actual scale interval. Exception to the rule are multiple range and multi-interval instruments having more than one actual scale interval. Such designs are not common, nevertheless one can come across them while operating customized industrial solutions.

Verification Scale Interval, e (weighing instrument)
Value, expressed in units of mass, used for the classification and verification of an instrument. Detailed requirements specified with regard to verification scale interval values are to be found in European Standard PN-EN 45501, or Directive 2004/22/EC (depending on the used measuring instrument). Generally it can be concluded that for equipment of accuracy class III d = e, whereas for equipment of remaining classes it is possible to apply solution where d ≠ e.

Readability
Readability of a weighing instrument is eqal to an actual scale interval.

Initial Verification
Legal Metrology procedure, carried out by legal authorities (Regional and District Offices of Measures) on the basis of acceptance tests of a particular weighing instrument model prior to putting it on the market. Since 1 May 2004 for most weighing instruments (including scales) the procedure can be replaced with conformity assessment procedure.

Subsequent Verification

Procedure to which only balances in use are subjected, in the course of the subsequent verification basic balance parameters are checked, i.e. they are compared with permissible threshold values. The procedure is carried out periodically in accordance with valid lawful acts. It is the user who is responsible for subjecting the device to the subsequent verification. One shall be aware of the fact that in the course of subsequent verification errors are referred to maximum permissible errors (MPE) thus prior to the procedure it is well worth to make sure that the indications errors are of lower values than MPE. With this it is guaranteed that the procedure ends in success.

CE Verification

Procedure within the scope of which the Notified Body checks and confirms that balance data are accordant with the type described in EC Type Approval certificate, and that they adhere to NAWI or MID Directive.

European abbreviation “EC” and Polish “WE” correspond each other and they stand for European Communities.

Module Type Approval (balances and scales)

With Module Type Approval the manufacturer is enabled to produce weighing equipment using modules: weighing terminal, load cell. The used modules are such ones that have been tested on a Notified Body premises and issued tests certificate. Particular modules for a given balance or scale are selected with reference to WELMEC-2 requirements.

EX Marking

EX Mark is a special symbol intended for products that have been designed to be operated in areas endangered with explosion. EX mark is applied to the device in order to inform that the particular product adheres to requirements of European standards corresponding with Directive 94/9/EC (ATEX Directive named by French phrase „ATmosphere EXplosible”).

Resolution

The smallest change in a quantity being measured that causes a perceptible change in the corresponding indication. For electronic balance it is presented by relation Max / d; i.e. 3000 g / 1 g = 3000 scale intervals.

Pre-packaged Product

Product intended for sale in an individual packaging of any kind, declared amount of which, dispensed in the buyer absence, cannot be modified when the packaging is closed, and for which any attempt of tampering is visible.

Automatic Weighing Instrument

Scale allowing to determine product weight without assistance of an operator, working in accordance with a set automatic cycle that is individually specified for a particular instrument.

Non-automatic Weighing Instrument

Scale by means of which the weighing process is carried out with assistance of an operator who loads and unloads the weighing pan, carries out taring, zeroing operations.

Minimum Capacity (Minimum Load)

Value of the load below which the weighing results may be subject to an excessive relative error. In accordance with regulations it is not forbidden to carry out measurements below the minimum capacity, nevertheless such measurements may feature greater error.

2.2. Conformity Assessment

In European Union the government has introduced a harmonized (unified) regulation concerning products manufacturing and trading – the law is superior to national law of the Member States. However in order not to produce too many detailed provisions that would have to be modified sooner or later as a result of technological development, technical regulation rules have been applied.

These so called "new approach" rules, unify those technical regulations which concern users safety and health, and protection of the environment. Unifying directives provide mostly general requirements to which given products are subjected, whereas technical details are specified by respective European standards EN, adherence to which is not obligatory.

The manufacturer may allege conformity of a given product with fundamental requirements of a directive, provided that the product has been manufactured in compliance with harmonized standard, symbol of which has been published in the Official Journal of the European Communities, and which standard has been transferred to national standards system of at least one European Union Member State.

As for alleged conformity, one shall bear in mind that it refers only to those fundamental requirements that are covered by a particular harmonized standard. It is crucial for the applied standards to correspond with all fundamental requirements referring to a particular product. It is not obligatory to apply harmonized standards ensuring alleged conformity. However those manufacturers who decide not to apply them, are obliged to prove compliance of a product with the fundamental requirements.

In case of some directives, product conformity with harmonized standards either simplifies conformity assessment procedure or supplies the manufacturer with a wider range of available procedures. As for the first instance, i.e. the simplified procedure, it does not require presence of the Notified Body. Products adhering to regulations specified by directives and associated standards are marked with CE marking and as CE-marked goods they can be put onto the market of any European Union Member State.

In 1989 the „new approach" has been supplemented with so called "global approach" to tests and certification. The supplementary approach specifies means for assessment of product conformity to provisions and standards, which means are obligatory for European Union Member States.

Within the scope of "global approach" eight fundamental modules were determined along with criteria for their selection. Each of the said modules can serve as a base for conformity assessment procedures described by particular directives. Additionally rules for CE marking application were specified.

CE marking symbolizes adherence of a particular product to those European Union regulations that refer to this very product. CE marking placed on an instrument proves that it complies with all European Union provisions to which the product is subjected, and that respective conformity assessment procedures were performed in the course of its qualification process.

If more than one “new approach” directives apply to a given product, then CE marking proves that the marked instrument complies with requirements of all the applicable directives.

When putting a new product on the European Union market, the manufacturer shall:

- specify to which “new approach” directives the product is subjected,
- carry out tests proving product conformity with directives; the test shall be carried out in accordance with proper directive-permitted modules,
- issue conformity declaration stating compliance with the directives,
- mark the product with CE marking.

Lack of adherence to the above guidelines means violation of Polish and European law.

Non-automatic electronic scales and balances, depending on their intended use and design, may be subjected to the below listed “new approach” directives:

- LVD (Low Voltage Electrical Equipment) 2006/95/WE,
- EMC (Electromagnetic Compatibility) 2004/108/WE,
- NAWI (Non-automatic weighing instruments) 2009/23/WE,
- MID (Measuring instruments) 2004/22/WE,
- MD (Machinery) 2006/42/WE.

LVD and EMC directives refer to each product put on the market, whereas NAWI and MID directives refer to weighing equipment **subjected to legal metrological control** (application specified by Article 8.1 of Law of 11 May 2001, *Law on Measures* – Official Journal of Laws 2013 item 1069).

Notified Body presence is not obligatory when carrying out conformity assessment in accordance with fundamental requirements of LVD and EMC directives – it is the manufacturer who can assess conformity on the basis of self-performed tests or tests that were performed by other institution.

Notified Body presence is obligatory when carrying out conformity assessment in accordance with fundamental requirements of NAVI and MID directives – it is the Notified Body that issues a certificate of EC type approval for a particular type series.

In order to assess conformity with NAWI or MID directives the manufacturer (with EC type approval certificate obtained) may adopt one of two following modules:

- Declaring conformity with EC type and warranty of product quality – procedure by means of which the manufacturer with implemented system of quality that is subjected to EC surveillance, declares that the weighing instruments are compliant with type described by type approval certificate and that they adhere to basic regulation-specified requirements.
- EC Verification – procedure by means of which the manufacturer declares that balances and scales tested by the Notified Body are compliant with type described by

type approval certificate and that they adhere to basic regulation-specified requirement.

RADWAG has obtained necessary permissions and while carrying out conformity assessment of self-manufactured products the company adopts the first module (i.e. *Declaring conformity with EC type and warranty of product quality*).

Diagram: conformity assessment for non-automatic weighing instruments

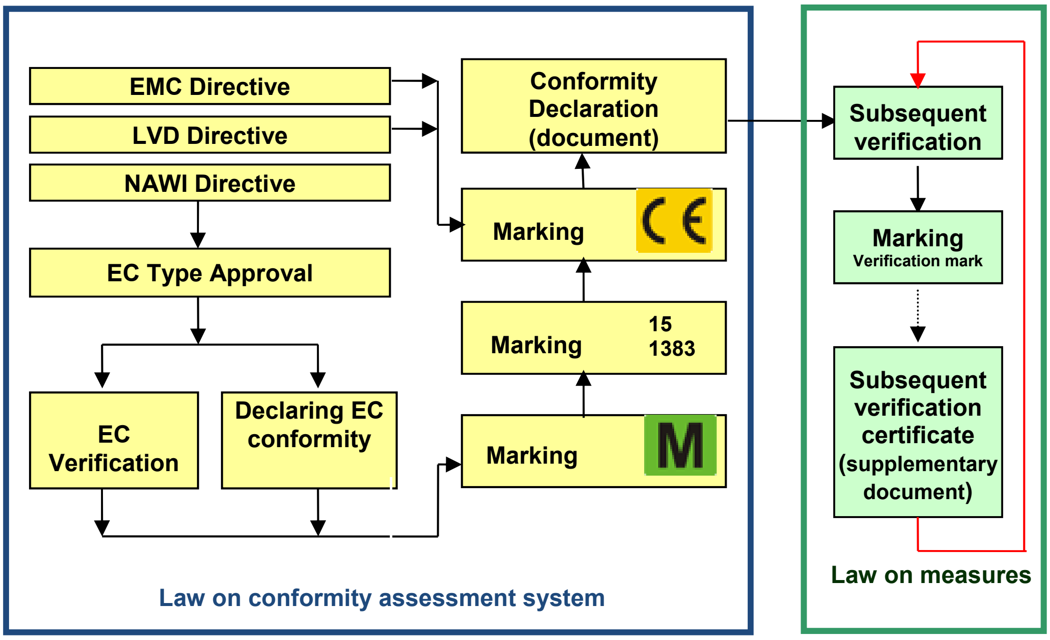

Fig. 1 Procedure for conformity assessment of non-automatic electronic weighing instruments

Pursuant to NAWI and MID directives, each scale or balance may be considered to be valid if the indications it produces are comprised within strictly determined limits set by the maximum permissible errors.

Non-automatic weighing instrument subjected to legal metrological control shall feature the following markings:

- CE mark

- two digits, adjacent to CE mark, standing for the last two numbers of a year when the mark was applied, and identification number of a Notified Body that carried out CE verification or of a Notified Body that is a supervisor of the manufacturer

  15

  1383

- green, square sticker with black capital letter M

Automatic weighing instrument subjected to legal metrological control shall feature CE mark, capital letter M and two last numbers of year when the mark was applied put in a rectangle, and identification number of a Notified Body:

CE $\boxed{\text{M 15}}$ 1383

Scales and balances with this kind of marking provided, shall have declaration of conformity with NAWI directive (non-automatic weighing equipment) or MID directive (automatic weighing equipment), which declaration is issued by the manufacturer.
EC conformity declaration shall provide:

- manufacturer's name and address,
- weighing instrument overview (model, type),
- reference to valid regulations,
- name of a person authorized to put signature on behalf of the manufacturer or the manufacturer's representative.

The manufacturer or the manufacturer's representative is obliged to keep copy of EC conformity declaration along with technical documentation.
EC conformity declaration aims to guarantee that a particular product, process or service complies with declaration-stated standard documentation, and to clearly indicate who is responsible for issuing particular qualification.

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CONFORMITY DECLARATION

Manufacturer: **RADWAG WAGI ELEKTRONICZNE**
Witold Lewandowski

Address: POLAND, 26-600 Radom, 28 Bracka Street

Non-automatic balances series: WPT; WPT/F; WPT/4F; WPT/4; WPT/4N; WPT/4P; WPT/4P2; WPT/2K; WPT/4I; WPT/P

We hereby declare in sole responsibility, that the designated product, marked with CE sign, fulfils the safety requirements of the European Directives:

Directive 2004/108/EC
Harmonized norms:
EN 61326-1:2006

Directive 2006/95/EC
Harmonized norms:
EN 61010-1:2010

Additionally, balances with the following symbols adjacent to CE sign:
- two last digits of the year, when CE sign was inserted and the number of notified body supervising over quality control system of the manufacturer
- green, square sticker with a black letter M

are conformable with the Type Approval Certificate EC no. T6496 and with:

Directive 2009/23/EC
Harmonized norms:
EN 45501:1992/AC:1993

Additional information:

- Type Approval Certificate EC no. T6496 issued by Notified Body no. 0122 NEDERLANDS MEETINSTITUUT
- Test Certificate for measuring indicator no. ZR 128/06-0050 issued by Notified Body no. 1383 ČESKÝ METROLOGICKÝ INSTITUT

With the authorisation of:
The Managing Director of RADWAG WAGI ELEKTRONICZNE – Dr. Eng Witold Lewandowski

Radom 02.01.2012	*Attorney for QMS Jacek Pilecki*	J. Pilecki
Place and date of issue	*Position, Name*	*Signature*

22/1/12/UK

Fig. 2 An exemplary conformity declaration for a verified weighing instrument

The above described markings completed with conformity declaration replace initial verification mark and initial verification certificate applied in Poland prior to 1 May 2004.

2.3. Weighing Instruments and Metrology

Each weighing instrument (non-automatic or automatic) intended to measure mass in an institution shall be subjected to metrological control. Metrological control can be divided into two basic categories:

- Obligatory control – based on respective regulations (subsequent verification), required for certain applications.
- Voluntary control – based on calibration and/or weighing instrument test carried out using a particular reference mass.

Please mind that *calibration* and *subsequent verification* are notions often used interchangeably, in fact they refer to completely different areas of metrology. *Calibration* is an activity associated with industrial metrology, whereas *subsequent verification* with legal metrology.

As far as weighing equipment terminology is concerned one can encounter definitions of various types. When it comes to terminology referred to general and legal metrology, it is supplied by previously mentioned international vocabularies of terms. Some concepts are defined by means of so called common definitions.

2.3.1. Legal Metrology – Subsequent Verification

Subsequent verification is a notion of legal metrology system, based on Polish and European regulations. Legal metrology system valid in Poland was implemented by law of 11 May 2001, *Law on Measures* (Official Journal of Laws 2013 item 1069).

Legal metrological control is intended for weighing equipment used for specified applications and areas of use:

- health, life and environment protection,
- safety and public order,
- consumer's right protection,
- charges, taxes and other than taxed dues, setting discounts, penalties, earnings and compensation as well as collecting and setting likewise receivables and benefits,
- customs service controls,
- trade.

Weighing equipment providing weight value for the above listed areas of use shall be subjected to subsequent verification upon conformity assessment and prior to being put on the market. This procedure is carried out by offices of measures.

The subsequent verification does not provide the user with information on real error values of a given instrument, it only informs that the errors are not greater than the maximum permissible errors. The maximum permissible error values for subsequent verification and for conformity assessment are likewise.

It is the user who is responsible for subjecting the instrument to the subsequent verification. In accordance with valid regulations the weighing instrument must be verified again in the following cases:

- end date of period for reporting the instrument to the first subsequent verification upon completed conformity assessment procedure,
- end date of subsequent verification validity,
- upon repair,
- damaged verification marks (difficult to read).

Period for reporting the instrument to the first subsequent verification upon completed conformity assessment procedure lasts 3 years. It starts on 1st December of the year when the conformity assessment procedure was carried out, i.e. when the marking was applied on the instrument. Subsequent verification is valid for 25 months, and it starts on the on the first day of a month when it was performed.
Evidence for the subsequent verification are subsequent verification marks or subsequent verification marks along with subsequent verification certificate.

2.3.2. Scientific and Industrial Metrology – Control over Weighing Equipment, Calibration

When it comes to industry, metrology is a multifaceted notion characteristic for various areas of industry-related activities – from designing and testing, through control of components and interoperation controls, to final quality control. Weighing instruments' users are obliged to keep the utilized equipment under supervision. The supervision shall cover control of general technical state of a particular device plus it shall monitor whether the user or law specified regulations with regard to the given instrument are met.
Pursuant to applicable provisions for management systems (standard and branch specified requirements), the weighing instruments must enable reference to international system of SI units by use of national mass standards (in Poland by means of mass standards maintained by Central Office of Measures).
In a modern world with an omnipresent globalization phenomenon it is hard to imagine consequences of lack of unification when speaking of everyday use of measuring units. Having realized that fact, it is obvious that traceability is an extremely significant issue for measurement.
Weighing equipment operated at any branch of industry is respectively supervised to various extents.
Institutions with implemented certified management systems apply relevant instructions or procedures informing the users how to properly operate equipment used for monitoring and measuring.
The standards refer to weighing equipment by separate chapters dedicated directly to the instruments but also by chapters specifying requirements for performance of the measurement. One of such examples is the most popular standard for quality management systems, ISO 9001, which comprises section covering guidelines for equipment designed to enable monitoring and measurement operations, i.e. section 7.6. In accordance with the requirements of ISO 9001, the institution shall specify scope of monitoring and measurements to be carried out, as well as the equipment for performance of the above, guaranteeing production of requirements-compliant product. Both monitoring and measurements are related to requirements imposed for the product. The institution shall establish customer-specified demands, including demands with regard to the delivery and

post-delivery actions, other than customer-specified demands, essential when it comes to particularized or intended use of the product, demands put forward by the law and product-related provisions plus any self-specified requirements.

System standards' guidelines coordinate traceability issues. The institution is supposed to set processes ensuring that both monitoring and measurements can be, and are carried out using method that provides adherence to requirements for monitoring and measurements.

By monitoring term one shall understand operation consisting in observation and supervision carried out by means of monitoring tools, i.e. control survey providing non-quantitative results. When speaking of measurements, set of actions is meant, which set of actions allows to determine quantity, size or dimensions using measuring equipment. For instance, these may be weighing operations carried out by means of an electronic balance or scale providing a particular physical quantity of weighed substance or product as an outcome.

In order to provide reliable results, the measuring equipment shall:

- be calibrated or tested within specified time intervals or prior to use, the calibration must be performed using such mass standards that refer to international or national mass standards; the calibration must be carried out in a competent calibration laboratory intended for appropriate physical quantity, accredited one the best – list of accredited calibration laboratories can be found on a website of Polish Centre for Accreditation, www.pca.gov.pl; calibration is a process of comparison wherein the measuring equipment of a particular company is compared with reference standards; the comparison aims to determine how accurate and reliable a particular equipment is, it also determines if the tested equipment is appropriate for performance of measurements in compliance with particular requirements specified for a given case; calibration shall be carried out as often as specified and within given time intervals;
- adjusted or readjusted, when needed; the equipment can be adjusted by a user, if only there is such technical possibility, or by an authorized service of particular device manufacturer;
- be provided with identification enabling calibration status to be specified; guidelines for identification can be found in standard ISO 10012;
- protected against accidental adjustments that could invalidate measurement results; most frequently used form of protection are protective labels applied by manufacturers, deliverers and by metrological service of a particular organization;
- protected against damage or deterioration of equipment state possible to occur in the course of transportation, maintenance activities or when stored in inappropriate conditions; it is advisable to follow user manual guidelines, workstation instruction and good practice recommendations.

Whenever verification of measuring equipment proves lack of compliance with requirements, the company shall assess, and record, reliability of previously performed measurements. What is even more, the company shall take respective measures concerning measuring equipment and manufactured products that could be affected by the said inconvenience. Any actions taken shall be documented.

When it comes to pharmaceutical companies the situation is slightly different. The said companies are subjected to regulation of Minister for Health of 1st October 2008 dealing with issues of Good Manufacturing Practice.

An appendix to the above regulation, in section 3 point 3.41, informs that measuring, weighing, recording and monitoring devices shall be calibrated and tested by means of dedicated methods, wherein the calibration is performed in specified time intervals and recorded for future reference. Clause 3 of the regulation, point 23, provides definition of calibration stating that it is a procedure aiming to determine relation between value indicated by a weighing instrument or weighing system and value obtained as a result of physical measurement, which values are next compared to known reference standard mass values. The discussed definition corresponds with definition for ADJUSTMENT, supplied by an *International Vocabulary of Metrology. Basic and General Concepts and Associated Terms* (PKN-ISO/IEC Guide 99) – def. 2.39.

Analysing the definition and system standards content, it can be concluded that non-obligatory requirements for pharmaceutical companies have been transferred into lawful regulations. This makes one easily realise how important measuring equipment issues are.

Monitoring of the equipment is the most important obligation with regard to weighing instruments. When it comes to companies owing a management system accordant to standards, e.g. ISO 9001, they shall study point 7.6 of the said document.

For each measuring device a record card with the following information shall be supplied:

1. identification of a particular unit of equipment and its software,
2. manufacturer's name, type designation and serial number or other individual marking,
3. test results proving that the equipment is accordant with specification,
4. current location of measuring equipment, if applicable,
5. user manuals supplied by the manufacturer, if available, or information on their location,
6. dates, results and report copies as well as any available calibration certificates, adjustments, acceptance criteria and subsequent calibration date,
7. maintenance schedule, if applicable, and already performed maintenance works,
8. each damage, faulty operation, modification or repairs.

All the records are stored by companies in a form of documents taking various names, e.g. "Device life card", "Device log". Thanks to such documentation the person responsible for metrological control, and also an auditor, can easily view procedure for control over measuring equipment.

Internal audits performed by external auditors, in accordance with an arranged calibration and measuring equipment checks schedule, shall include points referring directly to the measuring equipment.

One could ask how an audit shall be performed and where proves for performed equipment audit can be found.

The first source of information on equipment is its documentation. Respective documentation can consist of:

- device life card (named differently); device life card features any information identifying a particular instrument next to information on metrological approvals (calibrations and tests), repairs – if applicable, maintenance or additional adjustments and information on the device location;

- user manual supplied by the manufacturer or the distributor; it is a standard procedure to keep an original version of the user manual that is a base for designing a workstation instructions or brief manuals. This is especially important for the fact that numerous measuring devices feature supplementary functions that are not used by a particular company on a regular basis;
- calibration certificates;
- EC conformity declaration for devices subjected to legal metrological control (equipment purchased later than on 1st May 2004); these documents shall be kept since they are necessary for control purposes, wherein the control is performed by state bodies, besides they are required for subsequent verification carried out after conformity assessment (legal metrology regulations).
- verification marks or subsequent verification certificates for devices subjected to legal metrological control (equipment purchased prior to 1st May 2004); likewise for EC conformity declaration these documents are required for control purposes, wherein the performed control concerns legal metrology applications.

The second source of information is the very equipment featuring metrological status confirmation. The label shall contain any required information that must be readable.

Presence and accessibility of a user manual on a workstation (if practical) can be checked. Prior to such control the auditor shall analyse regulations referring to distribution and accessibility of user manual.

Additionally, general technical state of the particular weighing instrument and operational skills of respective personnel may be subjected to control.

Another source of information on weighing instrument are particular records obtained in the course of audit, these may concern:

- maintenance, service and metrological approvals;
- results of measurements performed while testing;
- calibration certificates;
- personnel authorization;
- Health and Safety guidelines (if necessary);

Any data on particular workstation ambient conditions is found to be the fourth source of information. The auditor may be interested in information referring to respective parameters (e.g. temperature, humidity). Auditor controlling technical aspects may also want to check if any measures for elimination of disturbance factors have been taken (e.g. application of anti-vibration tables).

The above examples specify where exactly proves for audits may be looked for, based on these any company may determine its own sources for audit information.

When speaking of weighing instruments used in industry, one has to remember about permanent documented monitoring of the device operation where basic metrological activity is calibration and periodical testing of the particular devices.

The weighing equipment must be calibrated in a competent calibration laboratory, preferably accredited one. When it comes to instruments and mass standards, weights and sinkers, it is possible to use services offered by an accredited Measurement Laboratory being a branch of RADWAG Metrology Centre organization.

It is very important to be aware of the fact that the supervision is not only about satisfying metrological characteristics criteria, although there is no doubt it is the most important

issue. Apart from the metrological characteristics, attention shall be paid to particular manufacturing, testing or measuring workstation infrastructure, including personnel skills as far as operation and utilization of a particular weighing equipment is concerned. One of many various tools guaranteeing personnel's professionalism are trainings. As for weighing equipment the users can attend trainings and workshops organized by RADWAG Metrology Centre.
Any data acquired in the course of supervision over the equipment, may be used for preparation of future orders specifications and for evaluation of the suppliers.

2.4. Weighing Instruments Classification

It is more than just functionality that shall be considered while selecting the instrument in order to make it suit particular working conditions and process. When it comes to technological processes requiring certified weighing instruments, classification specified by NAWI and MID directives must be taken into account. It happens quite frequently that balance or scale certified with reference to NAWI directive is used in an **automatic weighing process**, which is against valid regulations and may form basis for an auditor to question such device use. Avoiding this kind of mistake requires greater awareness, especially when speaking of automated industrial processes, therefore a special attention should be paid to class of a given scale or balance that is to serve for the purposes of a particular manufacturing or control process.

There are two basic categories of weighing instruments:

- non-automatic scales and balances – certified in accordance with NAWI directive,
- automatic scales and balances – certified in accordance with MID directive.

Definitions provided by NAWI and MID directives specify to which category a given instrument belongs to.

Fig. 3 Non-automatic weighing instrument

NAWI directive defines the <u>non-automatic weighing instrument</u> explaining that it is a device requiring **operator's assistance** in the course of the weighing process; e.g. loading or unloading the weighing pan or performing operations providing display of a result.

Fig. 4 Automatic weighing instrument

MID directive defines the <u>automatic weighing instrument</u> stating that it is a device determining the mass of a product **without the intervention of an operator** and following a predetermined programme of automatic processes characteristic of the instrument.

The distinction between these two definitions is not a case of an incident, it is not an artificial creation either. The said distinction is a result of characteristics of particular weighing instruments' working conditions. It is also an effect of control procedures and certification regarding the given device.
Non-automatic weighing instruments call for presence of the operator in the course of a measurement, the operator monitors the scale, he or she checks whether the instrument indicates zero prior measurement performance, decides when to confirm the indication or when to remove the weighed product form the weighing pan. Automatic weighing instruments in contrast, do not allow any of the above therefore they require the control functions to be in-built. Due to this the automatic weighing instrument is subjected to different certification and testing procedures.
Non-automatic weighing instruments allowing performance of specific operations, e.g. calculation or labelling, are additionally subjected to some supplementary tests which aim to control their non-standard functions, however in terms of metrological requirements such devices are likewise. The case is different for automatic weighing instruments. The division here, due to precisely specified application of a particular instrument type, is a much more complex issue.

According to MID directive the automatic weighing instruments are divided into:

- **Automatic catchweigher for single loads**
  An automatic weighing instrument that determines the mass of pre-assembled discrete loads (for example pre-packages) or single loads of loose material.
- **Automatic checkweigher**
  An automatic catchweigher that subdivides articles of different mass into two or more subgroups according to the value of the difference of their mass and a nominal set-point.
- **Weight labeller**
  An automatic catchweigher that labels individual articles with the weight value.
- **Weight|price labeller**
  An automatic catchweigher that labels individual articles with the weight value, and price information.
- **Automatic gravimetric filling instrument**
  An automatic weighing instrument that fills containers with a predetermined and virtually constant mass of product from bulk.
- **Discontinuous totaliser (totalising hopper weigher)**
  An automatic weighing instrument that determines the mass of a bulk product by dividing it into discrete loads. The mass of each discrete load is determined in sequence and summed. Each discrete load is then delivered to bulk.
- **Continuous totaliser**
  An automatic weighing instrument that continuously determines the mass of a bulk product on a conveyor belt, without systematic subdivision of the product and without interrupting the movement of the conveyor belt.
- **Rail-weighbridge**
  An automatic weighing instrument having a load receptor inclusive of rails for conveying railway vehicles.

In case of the first four types the metrological requirements for them are the same, the types differ only in terms of testing procedures that aim to control their additional functions: subdividing, labelling and price calculation. These are all scales for single loads.
As for the remaining types, they vary when it comes to certification and control procedures and also with regard to the permissible errors.

2.5. Weighing Operation and Maximum Permissible Errors

Deviations from model indications are commonly called errors and they accompany every single measurement. If such error value is smaller than the max permissible value regulated by law then the instrument is to be considered valid.
Values of max permissible errors depend on verification scale interval *e* and on accuracy class.

2.5.1. Non-automatic Weighing Instruments

Basic information concerning maximum permissible errors is presented in the below table:

Maximum permissible errors on verification	For loads, m, expressed in verification scale intervals, e			
	Accuracy class			
	I	II	III	IIII
± 0.5 e	0 < m ≤ 50 000	0 < m ≤ 5 000	0 < m ≤ 500	0 < m ≤ 50
± 1 e	50 000 < m ≤ 200 000	5 000 < m ≤ 20 000	500 < m ≤ 2000	50 < m ≤ 200
± 1.5 e	200 000 < m	20 000 < m ≤ 100 000	2000 < m ≤10 000	200 < m ≤ 1000

Table 1 - Maximum permissible errors for non-automatic scales by PN-EN 45501

Markings: e – verification scale interval
m – mass expressed in verification scale interval units

In practice scales of the following accuracy classes are operated: I, II, III. See the table below:

Accuracy class	**Marking**	**Intended Use**
Class 1 Special accuracy	I	Analytical
Class 2 High accuracy	II	Laboratory
Class 3 Medium accuracy	III	Applied mainly in industry and for trade settlements, sometimes in laboratory for less precise measurements

Table 2 - Non-automatic scales classification

There are cases where in accordance with metrological regulations the scale used for particular purposes does not require legal supervision (Directive 2009/23/EC) however such supervision may be needed due to some specific provisions of a given plant. Attention must be paid to such individual requirements.

EXAMPLE OF ASSESSMENT OF VERIFIED WEIGHING INSTRUMENT'S ERRORS

Application of legal metrology requirements is presented in an example of PS 360.R2 balance.

Technical specifications

Maximum capacity	Max = 360 g
Minimum capacity	Min = 20 mg
Readability	d = 1 mg
Verification scale interval	e = 10 mg
Tare range	T = - 360 g
Operating temperature	10^0C – 40^0C

Max permissible errors for PS 360.R2 balance are presented in a table below.

Loads m, expressed in verification scale intervals	Load expressed in grams	Max permissible error expressed in verification scale intervals	Max permissible error expressed in scale intervals
0 e ≤ m ≤ 5 000 e	0 – 50 g	±0.5 e	± 5 mg
5000 e < m ≤ 20 000 e	50 – 200 g	±1 e	± 10 mg
20 000 e < m ≤ 36 000 e	200 – 360 g	±1.5 e	± 15 mg

Table 3 - Max permissible errors for PS 360.R2

***Caution**: errors occurring during balance operation can be even twice greater.*

One shall bear in mind that in the course of verification the errors are referred to the verification scale interval *e,* and the user does not know numerical values of the determined errors. In order to determine errors referring to the scale interval *d* it is necessary to **calibrate the** device, only with this respective laboratory will be able to determine the indication errors and measurement uncertainty.

2.5.2. Automatic Catchweigher for Single Loads
(OIML R51 Automatic Checkweighing Instruments)

Fig. 5 Catchweigher intended for single loads

Depending on intended use and functions, the catchweighers for single loads are divided into two categories X and Y:
Category **X** applies to instruments used to check pre-packages made up in accordance with the requirements of *Council Directive 89/676/EWG of 30 December 1989 on the approximation of the laws of the Member States relating to the making-up by volume of certain pre-packaged liquids* and of *Council Directive 76/211/EWG of 20 January 1976 on the approximation of the laws of the Member States relating to the making-up by weight or by volume of certain pre-packaged products applicable to pre-packages*. This means that scales of category **X** are scales intended for performance of **pre-packaged goods control** in accordance with valid Law.
Category **Y** applies to all other automatic catchweighers for single loads.

These primary categories are further divided into four accuracy classes:

- XI, XII, XIII, XIIII
- Y(I), Y(II), Y(a), Y(b)

Additionally, in case of scales intended for pre-packaged goods control, the accuracy classes are supplemented by a factor (x), specifying multiplier of permissible limit value of standard deviation of experimental error (s), wherein the value of factor (x) cannot be greater than 2. Value of factor (x) is expressed in the form $1x10^k$, $2x10^k$, $5x10^k$, where k is a negative whole number or zero.

Exemplary marking of class of scale intended for control of pre-packaged goods:

XIII(1)

Exemplary marking of class of scale intended for use other than control of pre-packaged goods:

Y(a)

It is characteristic for automatic scales that in order to determine errors, a series of measurements is carried out, for which series the minimum quantity is determined by the legislator in implementing regulations. Depending on weight value the measurements quantity ranges between 10 and 60. When speaking of non-automatic weighing instruments, the quantity for the measuring series can be 1. Such procedure allows thorough testing of scales operation, more precisely the automatic weighing function and all related functions correcting effect of disturbances.

MID directive specifies **maximum permissible error** for automatic weighing instruments of category **Y**, it does so also for non-automatic devices, only the tested series quantity is different. In case of instruments intended for control of pre-packaged goods **maximum permissible error of average** and **maximum permissible standard deviation** are determined for the measuring series. These requirements show that for devices of this type single measurement error is not determined, which is a fundamental difference in comparison to non-automatic solutions.

Maximum permissible errors of average for instruments of category X and Y:

Net weight value (m) expressed in verification scale intervals (e)								Maximum permissible values of average error	Maximum permissible errors (MPE)
XI	Y(I)	XII	Y(II)	XIII	Y(a)	XIIII	Y(b)	X	Y
0 < m ≤ 50000		0 < m ≤ 5000		0 < m ≤ 500		0 < m ≤ 50		± 0.5 e	± 1.0 e
50000 < m ≤ 200000		5000 < m ≤ 20000		500 < m ≤ 2000		50 < m ≤ 200		± 0.1e	± 1.5 e
200000 < m		20000 < m < 100000		2000 < m < 10000		200 < m < 1000		± 1.5 e	± 2.0 e

Table 4 - Maximum permissible errors for instruments of category X and Y

Net weight of load (m)	Maximum permissible standard deviation for instruments of category X (I)
m ≤ 50 g	0.48 %
50 g < m ≤ 100 g	0.24 %
100 g < m ≤ 200 g	0.24 %
200 g < m ≤ 300 g	0.48 %
300 g < m ≤ 500 g	0.16 %
500 g < m ≤ 1 000 g	0.80 %
1 000 g < m ≤ 10 000 g	0.08 %

Table 5 - Maximum permissible standard deviation for instruments of category X

2.5.3. Automatic Gravimetric Filling Instrument

(OIML R60 Gravimetric Filling A.W.I.)

Fig. 6 Gravimetric filling instrument

Gravimetric filling instrument, called also dosing scale, is most frequently applied in filling systems that dispense loose products and liquids into single packaging; for example into mortar bags, barrels with oil, etc.

Gravimetric filling instruments include any type of multihead weighers.

These weighing machines, commonly called multihead combi weighers, comprise a logic device and 4, 16, 20 or 24 weighing buckets that enable static weighing of small portions. The logic device using mathematical algorithm selects from obtained samples few single mases, which in total give the required weight. Solutions of this kind usually cooperate with packing systems to which measured product is transferred.

In these weighing instruments the weighing operation takes place prior packing, therefore there is always the risk that not complete amount of product gets packed. Due to this the multihead weighers are not used for control of pre-packaged goods. They only serve as process facilities.

Systems of this kind often feature type approval accordant with NAWI directive, which disqualifies them as control devices allowing packing, and as instruments enabling law compliant control. Verification in this case makes no sense since use of such weighing instrument is not accordant with valid regulations. Besides, the packaging of a weighed product during the weighing operation remains open, which is against requirements of pre-packaged goods control.

Many manufacturers try to deal with this problem by using external control system that supervises the instrument's operation, which system serves as a kind of an electronic operator, however such approach is rarely accepted by respective administration bodies responsible for inspection.

In case of automatic gravimetric filling instrument there are two accuracy classes designated by the manufacturer:

- reference accuracy class Ref(x) corresponding to the best possible accuracy class of a particular type of instrument performing static weighing,
- operational accuracy class X(x) taking into account filling characteristics, installation method, fill mass and efficiency, supplemented with factor (x) specifying multiplier of permissible limit value of standard deviation of experimental error (s), wherein the value of factor (x) cannot be greater than 2. Value of factor (x) is expressed in the form $1x10^k$, $2x10^k$, $5x10^k$, where k is a negative whole number or zero.

Value of the mass, m (g), of the fills	Maximum permissible deviation of each fill from the average for class X(1)
m ≤ 50 g	7.2 %
50 g < m ≤ 100 g	3.6 g
100 g < m ≤ 200 g	3.6 %
200 g < m ≤ 300 g	7.2 g
300 g < m ≤ 500 g	2.4 %
500 g < m ≤ 1 000 g	12 g
1 000 g < m ≤ 10 000 g	1.2 %
10 000 g < m ≤ 15 000 g	120 g
15 000 g < m	0.8 %
Caution:Note: The calculated deviation of each fill from the average may be adjusted to take account for the effect of material particle size.	

Table 6 - Deviation from average fill

For static loads under rated operating conditions, the MPE for reference accuracy class Ref(x), shall be 0.312 of the maximum permissible deviation of each fill from the average; as specified in Table 6; multiplied by the class designation factor (x).

2.5.4. Discontinuous Totaliser (Totalising Hopper Weigher)

(OIML R107 Discontinuous Totalising A.W.I.)

Fig. 7 Discontinuous totaliser

This group of instruments is often called filling devices. However here a kind of intermediate device is used, which device transfers the product, either loose or liquid, into packaging or some other container. The intermediate device itself is also subjected to weighing. Final weight value is a total weight of particular weighings, e.g. performed in the course of filling the wagons or trucks.

Discontinuous totalisers are divided into 4 accuracy classes: 0.2; 0.5; 1; 2.
Depending on the accuracy class, different values of maximum permissible error are allowed:

Accuracy class	Maximum permissible errors (MPE) for the total load
0.2	± 0.10 %
0.5	± 0.25 %
1	± 0.50 %
2	± 1.00 %

Table 7 - Maximum permissible errors for discontinuous totalisers

2.5.5. Continuous Totaliser

(OIML R50 Continuous Totalising A.W.I.)

Fig. 8 Continuous Totaliser

Continuous totalisers, called also conveyor scales, are instruments installed under conveyors transporting the material. In case of these instruments the measurement result is an outcome of many factors: temporary weight value, speed and size of the conveyor, time interval within which the measurement is performed.
The measurement is carried out continuously in the course of conveyor operation.

Continuous totalisers are divided into 3 accuracy classes: 0.5; 1; 2.
The following MPE values are specified depending on accuracy class:

Accuracy class	MPE for totalised load
0.5	± 0.25 %
1	± 0.50 %
2	± 1.00 %

Table 8 - Maximum permissible errors for continuous totalisers

2.5.6. Automatic Rail Weighbridges

(OIML R106)

Fig. 9 Automatic Rail Weighbridge

Automatic rail weighbridge is presently quite rarely used. It has been replaced with automatic weighing instruments of different type, i.e. with continuous totalizers, discontinuous totalizers and automatic catchweighers for single loads. These machines enable performance of much more precise measurement in the course of wagons loading and unloading. In case of rail weighbridge time-consuming logistics are required in order to obtain weight indication. Weighbridges are pit scales therefore they are susceptible to adverse ambient conditions.

These instruments are divided into 4 accuracy classes: 0.2; 0.5; 1; 2.

Maximum permissible errors for rail weighbridges concern weight of a single coupled or uncoupled wagon and weight of the whole train.

Accuracy class	MPE
0.2	± 0.10 %
0.5	± 0.25 %
1	± 0.50 %
2	± 1.00 %

Table 9 - Maximum permissible errors for rail weighbridges

2.6. Measurement Uncertainty in Practice

It is obvious that all the measurements are invariably characterised with their results uncertainty. Whenever providing measurement results for any physical quantities, it is necessary to give quantitative information on particular measurements accuracy. Any person using measurement results for work purposes needs such quantitative information to estimate results reliability. Lack of this kind of information prevents possibility of comparing the results, one to another or to reference values specified by standards. Realising the above, it may be concluded that calculation of measurement uncertainty is indispensable.

Even after calculating all known or expected error components and after making respective corrections, it is still uncertain if the obtained result has been calculated correctly, plus it can be doubted whether the measurement result is representative for the measured quantity value.

The ideal method for estimation and expressing measurement uncertainty shall be universal so that it could be applied for any type of measurement and any type of input data used in measurements.

Various industrial and commercial solutions (for health care and safety) quite commonly provide weighing results range, which range almost entirely covers dispersion of values that justifiably can be attributed to the measurand.

Although error and error analysis have been constituting part of metrology for a long time, uncertainty, as a characteristic feature expressed in a numerical form, is a quite new notion in the history of measurement.

Uncertainty is an integral part of the measurement and as such it coexists with measurement results and tests. In recent years a considerable attention has been paid to this parameter, it concerns typical laboratory and industrial measurements, but also analysis of other results (e.g. control of articles delivered for production purposes).

What shall one understand by measurement uncertainty notion? An *International Vocabulary of Metrology - Basic and General Concepts and Associated Terms* defines *uncertainty of measurement* as a parameter, related to the measurement result, characterising dispersion of the quantity values being attributed to the measurand, based on the information used.

Standard deviation, or SD multiple, may be considered to be such parameter – note that standard deviation of series of measurements is uncertainty itself. Here we approach division of uncertainty in regard to parameters origin, the uncertainty can be divided into two types, type A and type B.

Uncertainty of type A

Type A method for calculation of standard uncertainty is based on analysis of statistic series of measurement results. In this case standard uncertainty is standard deviation. The method requires respectively great number of measurements to be repeated and it is applied to random errors. Type A method is used when it is possible to perform several measurements of the same load, wherein the measurements must be repeated for the same ambient conditions. Measurement of electronic balance repeatability is a good example for type A uncertainty. Series of 10 (or any other number) measurements is performed for a specified measuring point (in accordance with PN-EN 45501:1992, the measuring point shall be as close to maximum capacity as possible). It is important to perform the series of measurements using one and the same mass standard within a relatively short time interval. Additionally the measurements shall be carried out by one operator and stable ambient conditions must be provided.

Having completed the measurements, the standard deviation can be calculated using the below equation:

$$s(x) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where: n – number of measurements

x_i – result of the measurement

$\bar{x}$ – mean value of the measurement result for n measurements, calculated in accordance with the following equation:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Both of the above equations are commonly known and used for measurement analysis.

For type A uncertainty normal distribution is applied. It is presented in a graphic form by means of Gaussian curve. Such curve can be experientially determined for a great number of measurements (e.g. $n >= 400$). This is a good example to be used for training purposes when teaching about measurement. It shall help any unexperienced person to understand the phenomena.

Measurement uncertainty includes numerous components. Just like it has been presented above, some may be determined on the basis of distribution of statistic value of measurement series, and they can be characterized by a standard deviation. Other components, characterized by standard deviation likewise, are determined on the basis of expected probability distributions, estimation of which is based on experience or other data. This brings us closer to type B uncertainty.

Uncertainty of type B

Type B uncertainty is estimated by means of scientific analysis based on any available information concerning variation of input value. The information may include: data obtained in the course of previously performed measurements, experience, particular material nature and measuring tools specification. It is also common to use information taken from the manufacturer-prepared documentation, and uncertainty related to reference data specified by handbooks, scientific articles or other sources. Calibration certificates of measuring devices, physical quantities standards or other certificates supply as much important information.

For an electronic device, it is possible to estimate the following components of type B uncertainty:

- scale interval *d*,

- repeatability, characterized by standard deviation that has been determined by an operator earlier in the course of calibration process,
- error of indication, specified by a calibration certificate,
- uncertainty of estimation of indication error.

Of course an in-depth analysis may reveal other parameters, nevertheless these may not affect the uncertainty value (it depends on measurement accuracy whether they will or not).
When it comes to uncertainty of type B, rectangular distribution is the most frequently adopted one. As a result, in order to calculate uncertainty value, input data values have to be divided by $\sqrt{3}$. For a device with such resolution where maximum and minimum threshold of input value can only be assumed, the uncertainty is calculated by dividing the scale interval value by $2\sqrt{3}$. Uncertainty for estimation of indication error is calculated by dividing the expanded uncertainty (specified on a calibration certificate) by coverage factor *k* also specified on a calibration certificate. This make us approach remaining definitions, i.e. combined uncertainty and expanded uncertainty.

Combined uncertainty

Combined uncertainty - to speak as clearly as possible – is a combination of type A and type B uncertainty. In practice the person performing measurement usually deals with combined uncertainties, nevertheless there are some cases when the uncertainty analysis is nothing more than just analysis of type B uncertainty.
One of the parameters is so called sensitivity coefficient. This coefficient is related to input value and it is a partial derivative describing how output value estimate changes along with variation of input value estimate. This parameter is presented by the following equation:

$$c_i = \frac{\partial f}{\partial x_i} = \frac{\partial f}{\partial X_i}\Big|_{X_1=x_1 \ldots X_N=x_N}$$

where: c_i – sensitivity coefficient
x_i – input value estimate
X_i – input value

Contribution to the combined standard uncertainty is calculated by the following equation:

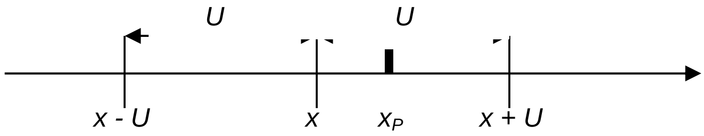
$$u_i(y) = c_i \cdot u(x_i)$$

where: $u_i(y)$ – contribution to the combined standard uncertainty
c_i – sensitivity coefficient
$u(x_i)$ – standard uncertainty

Expanded uncertainty

Expanded uncertainty is a quantity that defines measurement result range within which the value of the measurand can be confidently asserted to lie. The said range and spread of values (which values are rightly attributed to the measurand) may partly cover.

In accordance with an *International Guidance for Uncertainty of Measurement*, letter *u*, has been assigned for uncertainty whereas letter *U* has been assigned for expanded uncertainty. See the figure below for the measurement uncertainty presented in a graphic form:



where: x – measurement result

x_P – measurand

While performing measurement for x_P value, x result has been obtained. It can be easily observed that the measurement result value and the measurand differ – in practice there are no exactly precise measurement indications. It is possible only to specify a particular interval within which the measurand is contained. Measurement accuracy and uncertainty related to this measurement regulate how wide the said interval is. Both, accuracy and uncertainty are affected by used measuring equipment, ambient conditions, operator and correctness of performed measurement uncertainty analysis.

Coverage factor **k** is a number multiplied by the combined standard uncertainty in order to give an expanded uncertainty.

Expanded uncertainty is calculated by the following equation:

$$U = k \cdot u(x)$$

where: U – expanded uncertainty

k – coverage factor

u(x) – combined uncertainty

When spread of measured value may be described by normal distribution (Gaussian distribution), and if standard uncertainty related to output value estimate is sufficiently reliable than used coverage factor is $k = 2$. With such assumption, the expanded uncertainty gives a level of confidence of approximately 95%. These conditions are met for most cases when it comes to calibration – therefore international bodies have decided that laboratories carrying out calibration accredited by EAL members, will give expanded uncertainty *U*, obtained by multiplying estimate y of output value of standard uncertainty $u(y)$ by coverage factor $k = 2$.

When speaking of measurement uncertainty one shall remember that it is an effect of random errors that coexist with the measuring process. *Error of measurement*, as defined by an *International Vocabulary of Metrology - Basic and General Concepts and Associated Terms*, is a difference between measurement result and the true value of the measurand.

The dictionary specifies the following errors:

- *relative error*, defined as relation of error of measurement to the true value of the measurand,

- *random error* , defined as difference between measurement result and mean value of unlimited number of measurements performed for the same load under repeatability conditions,
- *systematic error*, defined as difference between mean value of unlimited number of measurements performed for the same load and a true value of the measurand. So called (*correction*) is a part of systematic error definition. The said correction is a value added to measurement result in order to compensate for the systematic error. It may be briefly described as error of measurement with an opposite sign.

Below you can study the least complicated example of measurement uncertainty estimation. For this, 5 g load has been measured by means of electronic balance with scale inteval 0.01 mg.

Following the procedures for estimation of measurement uncertainty, the first step to be taken is specifying measurement equation, the equation shall cover all influence factors.

For the discussed example the equation is as follows:

$$m = m_0 + \delta m_1 + \delta m_2 + \delta m_3 + \delta m_4$$

where: m – load that is being measured

m_0 – load that has been measured

δm_1 – spread of value

δm_2 – scale interval

δm_3 – error of indication

δm_4 – uncertainty of estimation of error of indication

After writing the measurement equation correctly, it is turn to write measurement uncertainty equation, and calculate uncertainty of all equation components:

$$u^2(m) = u^2(\delta\, m_1) + u^2(\delta m_2) + u^2(\delta m_3) + u^2(\delta m_4)$$

$$c_i = 1$$

Sensitivity coefficient in this case equals 1 for all uncertainty components. Now uncertainty of particular components for input values must be calculated:

– load that has been measured – m_0: with the sample on the weighing pan, the balance indication was 5000 mg (in order to make understanding as uncomplicated as possible the results are given in mg),

– spread of value – δm_1: standard deviation has been determined on the basis of few series of measurements, s = 0.02 mg,

– scale interval – δm_2: scale interval δ for the used analytical balance is 0.01 mg, this allows to conclude that uncertainty due to balance resolution equals:

$$u(m_2) = \frac{0.01\text{mg}}{2\sqrt{3}} = 0.0029\text{mg}$$

– error of indication – δm_3: calibration certificate for the used balance specifies +0.01mg error of indication for point 5g, with measurement uncertainty U = 0.02mg and with coverage factor k = 2. The uncertainties are calculated as follows:

$$u(m_3) = \frac{0.01\text{mg}}{\sqrt{3}} = 0.0058\text{mg}$$

$$u(m_4) = \frac{0.02\text{mg}}{2} = 0.01\text{mg}$$

Now it is time to compile all the results and use them to access uncertainty budget, owing to which it is possible to observe which uncertainty component affects the whole uncertainty the most (Table 10). Uncertainty value is determined as root of the sum of each standard uncertainty squared.

Value symbol	Value estimate	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to combined uncertainty
m_0	5000 mg	-	-	-	-
δm_1	0 mg	0.0200 mg	*normal*	1	0.0200 mg
δm_2	0 mg	0.0029 mg	*rectangular*	1	0.0029 mg
δm_3	0 mg	0.0058 mg	*rectangular*	1	0.0058 mg
δm_4	0 mg	0.0100 mg	*normal*	1	0.0100 mg
m	5000 mg			**Uncertainty**	**0.023 mg**

Table 10 - Example of uncertainty budget

In accordance with the procedure, expanded uncertainty *U* shall be calculated at this stage. With coverage factor *k* = 2 adopted, level of confidence is about 95%.

Using equation for expanded uncertainty, its value is calculated as follows:

$$U = k \cdot u_c(m) = 2 \cdot 0.023\text{mg} = 0.046\text{mg}$$

Final measurement result, i.e. balance indication for weighing of 5 g load is:

m = (5000.00 ± 0.05) mg

this means that the value is comprised within 4999.95 mg – 5000.05 mg range.

Measurement result uncertainty reflects lack of precise measurand value. Finding the exact quantity would require a great number of various data, due to this the attempt to obtain the precise masurand value is abandoned in practice. Influence factors affecting uncertainty, and at the same time preventing the measurement result from being expressed by means of one value, are regarded as sources of uncertainty. There are various sources of uncertainty, for example:

- incomplete definition of the measurand,
- imperfect accomplishment of measurand definition,
- imprecise sampling, i.e. measured value does not represent adequately the defined measurand,
- incomplete knowledge on influence of ambient conditions on measuring procedure or imperfect measurement of parameters characteristic for the ambient conditions,
- mistakes when reading indications of analogue devices,
- imprecise values of mass standard and reference weights,
- imprecise values of stable and other parameters, taken form external sources and used for data processing procedures,
- simplified approximations and assumptions used in measuring methods and procedures,
- dispersion of value of measurand, obtained in the course of observation repeated for potentially identical ambient conditions for several times.

Successfully accessed measurement uncertainty is a result of thorough and detailed analysis of the whole measuring process. It shall be remembered that not all equation components influence the measurement accuracy each time the uncertainty is accessed.

2.7. IQ, OQ, PQ

One of the first activities regarding design of a new research workstation, or workstation intended for performance of measurements, is selection of a right weighing device living up to operator's expectations. The requirements are usually specified by respective standards describing a given test or measurement procedure. However there are numbers of cases where it is the workstation designer who is obliged to select the most optimal weighing equipment.

Upon supplying the customer with the ordered instrument it is necessary to test it making sure that the delivered equipment, or measuring system, is compliant with the order, meets the requirements and operates correctly. Testing process is often called *measuring equipment qualification*. Only successfully competed qualification process enables the particular weighing instrument to be used in the course of performance of a given procedure, both test and measurement.

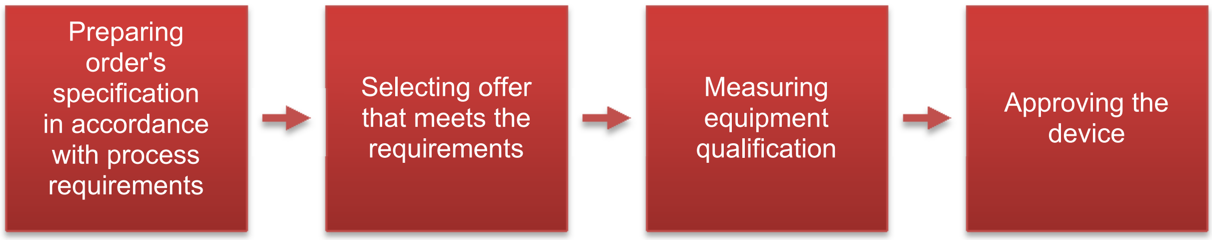


Fig. 10 Procedure to which the instrument is subjected prior use

Measuring equipment qualification concerns many research, measurement and production areas. Qualification is related to validation of testing, measuring or control procedures.

Analysis of standards and law documentation provide different definitions of validation. *International Vocabulary of Metrology. Basic and General Concepts and Associated Terms* (PKN-ISO/IEC Guide 99:2010), section 2.45, defines validation as *verification, where the specified requirements are adequate for an intended use.* Verification is defined here as *provision of objective evidence that a given item fulfils specified requirements.*
Section 5.4.5.1 of PN-EN ISO/IEC 17025:2005 standard states that *Validation is the confirmation by examination and a provision of objective evidence that the particular requirements for a specific intended use are fulfilled*.
Whereas section 3.8.5 of PN-EN ISO 9000:2006 standard, *Quality Management Systems. Fundamentals and Vocabulary,* provides the reader with the following definition: *validation - confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled.* This standard implies that validation can be carried out under real and replicated conditions.
The above definitions however different lead to one common conclusion. Namely, each of them clearly states that it is necessary to confirm and provide evidence proving that the applied test, measurement or control procedure complies with given requirements under particular conditions (environment, personnel, weighing equipment).

It has been already said that measuring equipment greatly influences measurements accuracy, due to this measuring equipment qualification is an extremely important element of the validation procedure.

Valid PUBLIC ANNOUNCEMENT OF THE MINISTER FOR HEALTH of 17th October 2013 concerning consolidated text of regulation of the Minister for Health regarding Good Manufacturing Practice requirements informs that *validation of the Process is a paper evidence proving that the process functioning within specified range of parameter values allows to effectively and repeatedly manufacture intermediate products or active substances that meet requirements of previously determined quality specifications.*

In accordance with the aforementioned document, prior taking up activities related to the process validation, it is necessary to complete qualification of critical instruments and supplementary systems.

Measuring equipment qualification comprises the following activities, wherein either all or some of them are carried out:

1. Design Qualification (DQ): documented test and confirmation stating that rooms, devices and installations design is respective and shall allow performance of intended operations.

When it comes to the weighing instruments the DQ means compliance with requirements for scales functionality and measurement accuracy.

2. Installation Qualification (IQ): documented test and confirmation stating that installed or upgraded weighing instruments or installations are compliant with accepted design, manufacturer recommendations or user requirements.

IQ covers the following issues:

- unpacking,
- compliance with the order,
- manufacturer documentation,
- verification of materials,
- environmental conditions,
- installation.

3. Operational Qualification (OQ): documented test and confirmation stating that installed or upgraded weighing instruments and installations operate correctly as intended for all anticipated operating conditions.

OQ covers the following issues:

- instrument start-up,
- tests and comparison of the results with adopted acceptance criteria, wherein the least favourable conditions are taken into account,
- cooperation with peripheral devices,
- training,
- periodical inspections and maintenance.

4. Process Qualification (PQ): documented test and confirmation stating that the weighing instruments and supplementary installations, combined into one functional system, are able to work effectively and in a repeatable manner in accordance with accepted specification process method.

PQ can be carried out along with OQ.

PQ covers the following issues:

- tests with use of real products or test products simulating the real ones,
- tests under conditions covering high and low operating limits.

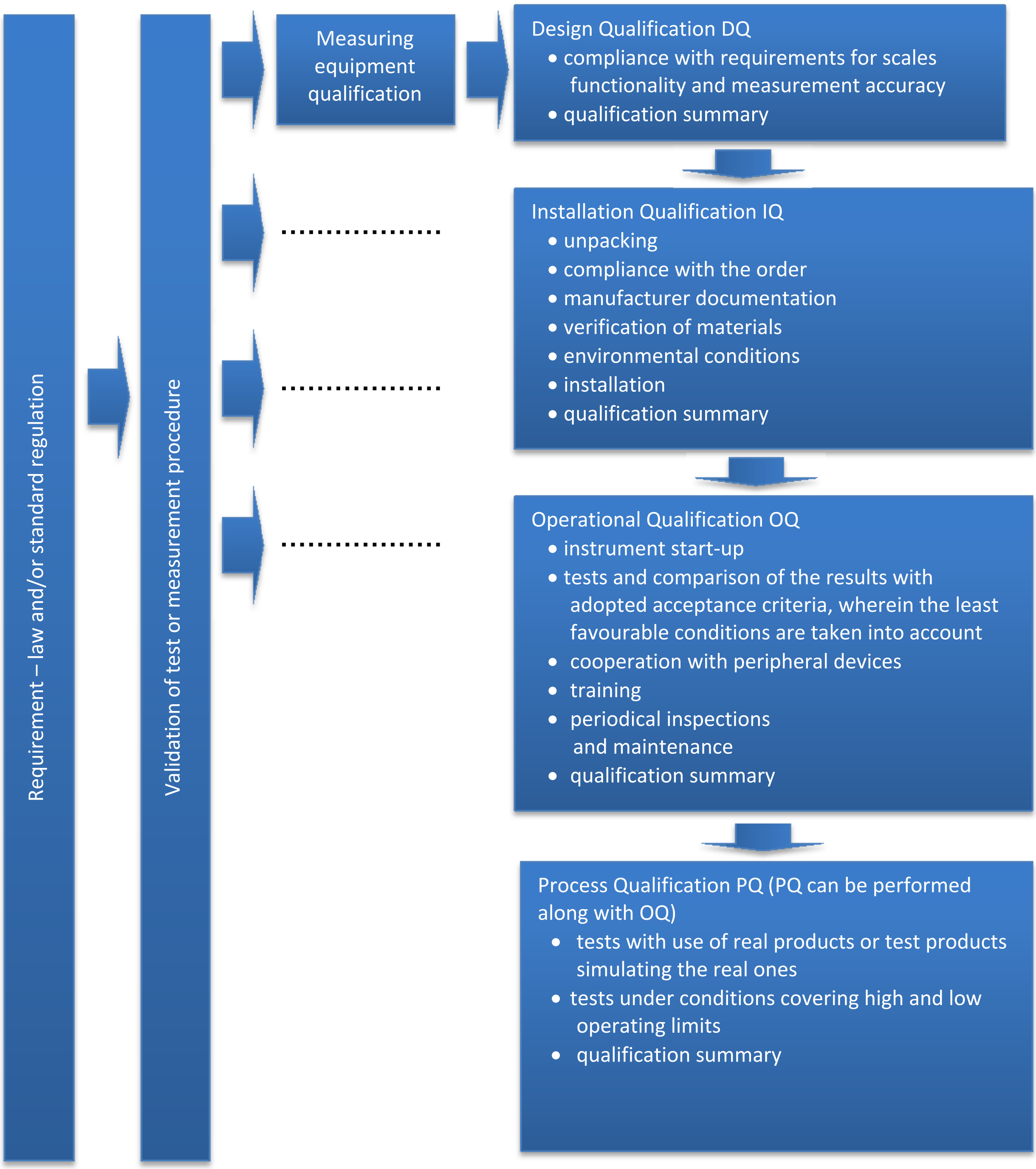


Fig. 11 Measuring equipment qualification as part of validation of test procedure

Qualification process documents

Qualification process documents shall comprise the following:

Qualification Protocol - document specifying how to carry out particular qualifications. It shall describe critical process stages and acceptance criteria.
The protocol must be assessed and approved by a quality department or some other team of employees, appointed to this task.

Qualification Report - document referring to a particular qualification Protocol, it shall provide obtained results summary along with remarks on observed deviations and respective conclusions including recommended corrective actions.
Any potential modification regarding the Qualification Protocol must be described with persuasive arguments put forward.
After successfully completed qualification, permission to carry out the next qualification-related stage shall be granted in a written form.

Having finished all the qualification operations, and potential actions aiming to find explanations to encountered problems, it is time for a final review of the complete documentation. The review is performed in order to check whether all the assumptions have been realised and whether the qualification was carried out trouble-free. Upon verification of the results, qualification summary is made and final conclusions regarding either negative or positive outcome are drawn.
When the measuring equipment qualification process ends, respective metrology experts identify the equipment and prepare Product Life Cycle Card (the card name may differ depending on the company).

laboratory logo	laboratory name
	PRODUCT LIFE CYCLE CARD

No. on the Log's list:	Device name:	Type:	Manufacture date:	Code:	Manufacturer:
		Storage place:		Serial no.:	Additional equipment:

No.	METROLOGICAL OPERATION PERFORMANCE DATE	METROLOGICAL OPERATION TYPE		PERFORMED BY	SUCCESSIVE METROLOGICAL OPERATION DATE		NOTES (defects, repairs, commissioning, etc.)
1.		CALIBRATION			CALIBRATION		
		TEST			TEST		
2.		CALIBRATION			CALIBRATION		
		TEST			TEST		
3.		CALIBRATION			CALIBRATION		
		TEST			TEST		
4.		CALIBRATION			CALIBRATION		
		TEST			TEST		
5.		CALIBRATION			CALIBRATION		
		TEST			TEST		
6.		CALIBRATION			CALIBRATION		
		TEST			TEST		
7.		CALIBRATION			CALIBRATION		
		TEST			TEST		
8.		CALIBRATION			CALIBRATION		
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10.		CALIBRATION			CALIBRATION		
		TEST			TEST		
11.		CALIBRATION			CALIBRATION		
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12.		CALIBRATION			CALIBRATION		
		TEST			TEST		
13.		CALIBRATION			CALIBRATION		
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14.		CALIBRATION			CALIBRATION		
		TEST			TEST		
15.		CALIBRATION			CALIBRATION		
		TEST			TEST		
16.		CALIBRATION			CALIBRATION		
		TEST			TEST		

*) In accordance with metrological operations schedule designed by the Manager

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Fig. 12 Exemplary product card

The product card shall provide the following compulsory data:

- identification number of the equipment and its software,
- manufacturer name, type designation and serial number or some other individual marking,
- test results showing whether the equipment complies with the specifications or not,
- current location, where appropriate,
- user manuals, where accessible, or information specifying where the user manual is to be found,
- dates, copies of inspection reports and calibration certificates, regulations,
- maintenance services schedule, where appropriate, and record of so far performed maintenance works, description of each damage or faulty operation, modification or repair.

To complete the qualification process documentation, measurement traceability shall be ensured, traceability is guaranteed by calibration of the measuring equipment.

Additionally, if possible, the monitored measuring equipment must be marked with labels, code or provided with identification of any other kind in order to present the device status. Determining the status, apart from qualification of course, may concern also calibration, testing or subsequent verification.

Periodical inspection of validated systems

The systems and processes shall be periodically evaluated in order to verify and approve that they continue to operate correctly, i.e. that they function as intended by validation.
If no significant modifications have been implemented either in the system or in the process, and if quality evaluation confirms that a given system or process provides products compliant with the particular specifications, then there is no need for revalidation.
This rule is applied also when it comes to subsequent qualification of the measuring equipment.

Measuring equipment qualification is obligatory in pharmaceutical industry and it is often performed in food industry. Nowadays it may also be present in other industry branches. This is an effect of requirements of quality systems and procedures, both guaranteeing correct performance of testing or manufacturing processes.

Modern weighing instruments and systems, especially those dedicated for industry, apart from the basic function, i.e. weighing, feature complex software enabling performance of complicated production procedures. They are equipped with databases, statistics modules, multi-level access rights, and passwords. Vast range of functions results with expanded qualification process of the measuring equipment. In such cases the said process is not limited only to tests of the weighing operation but sometimes it must be compliant with requirements of computerised systems qualification.

Qualification requirements may reflect requirements specified by the following documents:

- GMP Guidelines - Annex 15, Annex 11
- GAMP 5 Guide
- FDA – 21 CFR part 11
- ISO Standards

In case of a weighing instrument or a system featuring a high-tech communication interface and offering complex functionality, the qualification shall concern, apart from the weighing operation, also the following elements:

- clear user identification (unique access code)
- registering all non-authorized attempts of access to sensitive data
- restricted access to the system
- access rights granted with reference to particular process tasks
- control and safety of data entering and processing
- record of all GMP-sensitive modifications (generating „control log")
- identification of critical data e.g.: product code, product name, unit, serial number etc

Qualification team

Being familiar with the practices, it is necessary to visualise how to correctly carry out the qualification process of a particular weighing equipment. Experience shows that the most appropriate solution enabling performance of complex qualification is to establish qualification team, group of experts comprising among many, representatives of particular process user and measuring equipment manufacturer.

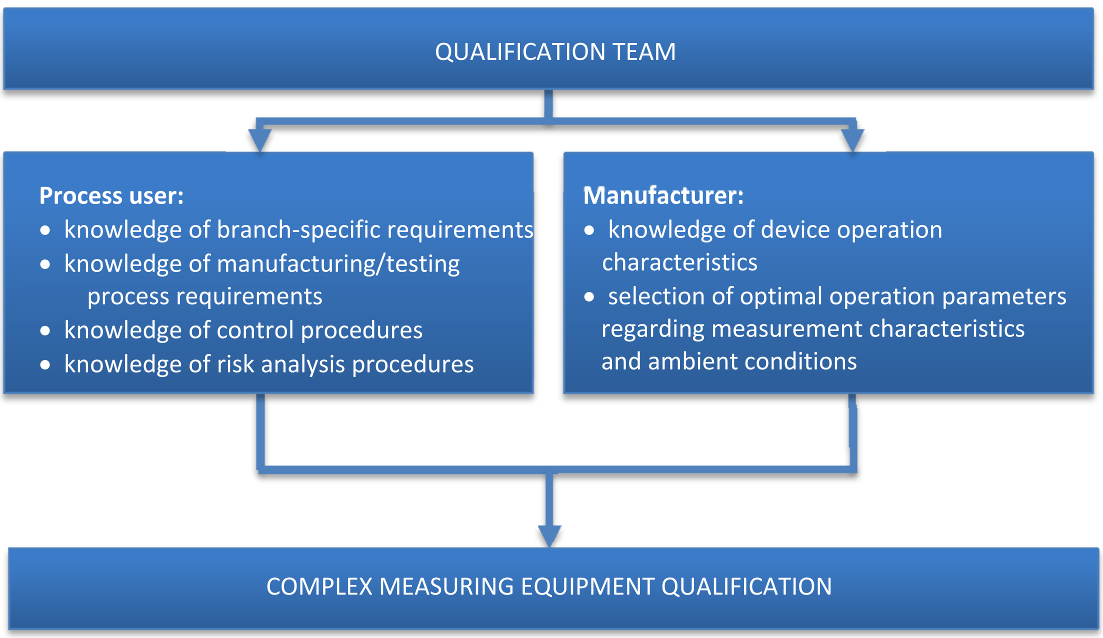


Fig. 13 Qualification team.

Process user representative has knowledge, both practical and theoretical, on the following:

- particular requirements characteristic for a given branch,
- testing, measuring, or control procedures and permissible limits,
- risk analysis procedures concerning particular testing, measuring or production process.

Manufacturer's representative has knowledge, both practical and theoretical, on the following:

- particular device operation characteristics,
- selection of optimal operation parameters regarding measurement characteristics,
- ambient conditions influencing the measuring process which facilitates potential errors compensation or optimisation of the conditions.

Combined knowledge of both representatives guarantees correct and successful process of measuring equipment qualification.

3. Mass Measurement Sensors

In most cases, mechanical solutions have been replaced by modern electronic mass measurement equipment. However, the equipment is not only based on electronic elements, but it consists of mechanical and electronic parts. Electronic one is installed on mechanical component or cooperates with it. This is due to a fact that large forces cannot be applied to electronic elements which are not intended for such actions. It may cause their immediate damage. Therefore, mass measurement operation is indirect. Mechanical element enables measuring applied force impact on the load-bearing part and then sends the result to the electronic part. Indirect operation of mass measurement causes measurement error being a result of mechanical component defects. Mechanical design of the sensor and the technology used to build it are crucial for manufacturers of sensors and weighing equipment. Therefore, in most cases their designs are protected by patent claims. The most accurate, complex and technologically advanced sensors are used in analytical balances and mass comparators.

Most measuring systems, e.g. load cells, measure the value of bending caused by applied force. The most accurate measuring systems measure force required to compensate applied mass and not the force value itself.

The sensors that are most commonly used in measuring equipment are presented further down this document.

3.1. Load Cells

Basic and the most widely used sensor is load cell, known also as strain gauge. Term 'strain gauge' applies to measuring system installed on a metal beam and not the sensor itself. However, both phrases are used interchangeably.

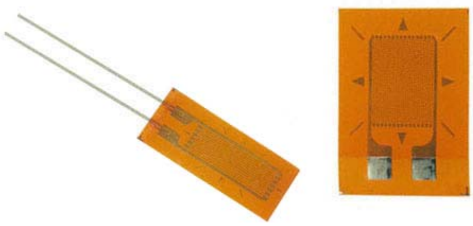


Fig. 14 Foil strain gauge

Depending on the application, there are different types of strain gauges. Such division is connected with measurement conditions, operating temperature, types of loads, material and shape of the surface to which strain gauge is stuck. The most widely used strain gauge is a resistance one that is stuck to steel or aluminium beam thereby creating a load cell. The resistance strain gauge has many advantages:

- relatively high sensitivity and accuracy,
- compact design,
- resistance to vibrations and shocks,
- wide range of operating temperature,
- possibility to be installed on uneven surfaces,

- low price.

Principle of resistance strain gauge operation is based on physical properties of resistance wire which resistance depends on its length. Therefore, the wire is stuck to the surface that bends depending on the applied force. Strain gauges are stuck using adhesives ensuring that deformation of the load-bearing part is identical with strain gauge deformation. The technology of sticking strain gauges and manufacturing load-bearing parts is a knowledge protected by manufacturers of load cells, because it influences final quality of a sensor.

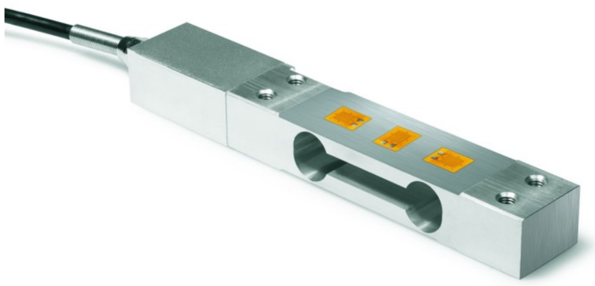


Fig. 15 Load cell with strain gauges stuck to it

Depending on the arrangement of resistance element, there are following types of strain gauges:

- serpentine - resistance wire has serpentine shape,
- grid shape - resistance wire arranged as parallel, both ends of the wire are connected together using thick conductive tape,
- foil - most widely used, the wire is shaped as a resistance grid made of thin foil stuck to supporting layer.

Depending on the type of metal load-bearing part, strain gauge can be used in sensors of both low and high capacity.

Fig. 16 Load cell of 10 kg capacity (left side) and of 30 t capacity (right side)

Load cells use change in ΔR resistance of a strain gauge against mechanical strain. The change is linear which simplifies calibration of the readout system.
Dependence between change in strain gauge resistance and mechanical strain is presented by the following formula:

$$\Delta R = kR\varepsilon = kR\frac{\Delta\sigma}{\mathrm{E}}$$

where: R - strain gauge resistance without strain
k - strain gauge constant
ε - relative increment
σ - strain
E - Young's modulus

The formula shows that relative deformation of the strain gauge is directly proportional to change in resistance. The value of k constant depends on material used for resistance wire and the following factors: wire arrangement, type of adhesive etc. The value of k constant is determined empirically. Constancy of k coefficient depends on diligence and quality of sensor's subassemblies.

Strain gauges used in load cells are connected together and form Wheatstone bridge circuit; in accordance with the following diagram:

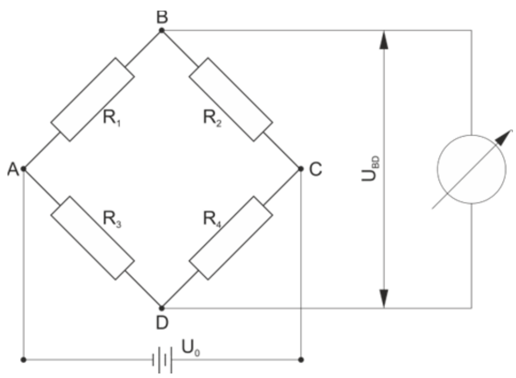


Fig. 17 Diagram of Wheatstone bridge circuit

Wheatstone bridge consists of four elements. In most cases those are: R1 strain gauge for measuring strain value, R2 compensatory strain gauge compensating influence of temperature and humidity changes, R3 and R4 compensating resistors. There are load cells for which more than one strain gauge is used. However, the main principle of operation remains the same.
Originally, load cells were powered with alternating voltage. For many years, alternating voltage amplifiers, due to uncomplicated design, were used instead of direct current amplifiers because of their technical problems. Nowadays, load cells are powered by direct current or rarely - by square wave.

Usually, load cell resolution ranges from 3000 to 6000 units, which means that sensor maximum capacity can be divided into 3000 to 6000 steps. Load cell resolution is determined based on certification tests in accordance with OIML R60. As a result of carried out tests, load cell is classified with class ranging from C3 up to C6 (there are other classes of higher resolutions, however load cells do not fulfil required certification criterions due to design limitations). The load cell can be used as part of verified weighing equipment which resolution cannot be greater than the class of used load cell.

Fig. 18 Load cell of WLC precision balance

Through selection, optimization and program correction it is possible to design weighing equipment of 60 000 - 100 000 resolution, but it can be done only for few types of applications. RADWAG has invented and implemented technology that enables to manufacture such devices. An example of aforementioned technology is WLC precision balance. The photo presents typical load cell being part of WLC 6/A2 precision balance.

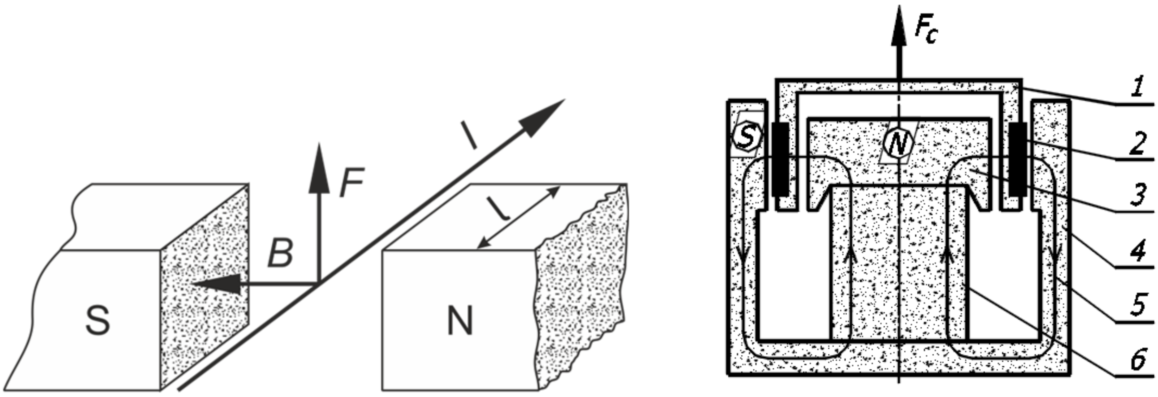
3.2. Magnetoelectric Converters

As opposed to load cells, which are the simplest sensors, magnetoelectric converters are more accurate and technologically advanced.

Massive production of load cells and using them in electronic balances resulted in high level of their development. However, design that would allow to carry out high resolution measurements have not yet been invented. It seems that technological development of load cells has reached its limit. New constructions are still created for specific applications and their resistance to ambient conditions is improved, but the accuracy remains unchanged.

For this reason, magnetoelectric converters, until recently used only in laboratories, are more often applied for industrial measurements. High accuracy, measurement speed and possibility to compensate start mass are their advantages. In case of using load cell of 10 kg maximum capacity and 5 kg weighing pan, measuring range is limited to 5 kg. In the matter of magnetoelectric converter, it is possible to compensate mass of the weighing pan and maintain unchanged maximum capacity. It is significant in case of industrial applications, since weighing equipment often features weighing platform in form of a heavy container or a conveyor.

In magnetoelectric converter the following effect is used: to conductor with current, placed in homogeneous magnetic field, electromagnetic force is applied, known also as Lorentz force (fig.19a).



F – Lorentz force vector
S – south pole of permanent magnet,
N – north pole of permanent magnet,
B – magnetic induction vector,
I – electric current vector,
l – conductor length in magnetic field

1 – coil carcass,
2 – coil winding,
3 – pole shoe,
4 – solenoid actuator body (magnetic circuit element),
5 – magnetic field lines,
6 – permanent magnet insert

Fig. 19 Principle of operation of solenoid actuator
a) conductor with current in magnetic field, b) cylindrical solenoid actuator

When directions of current and magnetic field are perpendicular to one another, the force is as follows:

$$F = I * B * l$$

where: I – current in conductor
B – magnetic field induction
l – conductor length

F force is perpendicular to conductor and its direction depends on direction of current. Electromagnetic converter, known also as solenoid actuator, is a cylindrical coil sunk in magnetic circuit gap with permanent magnet being its element (fig. 19b).

Fig. 20 contains diagram of balance equipped with electromagnetic converter.

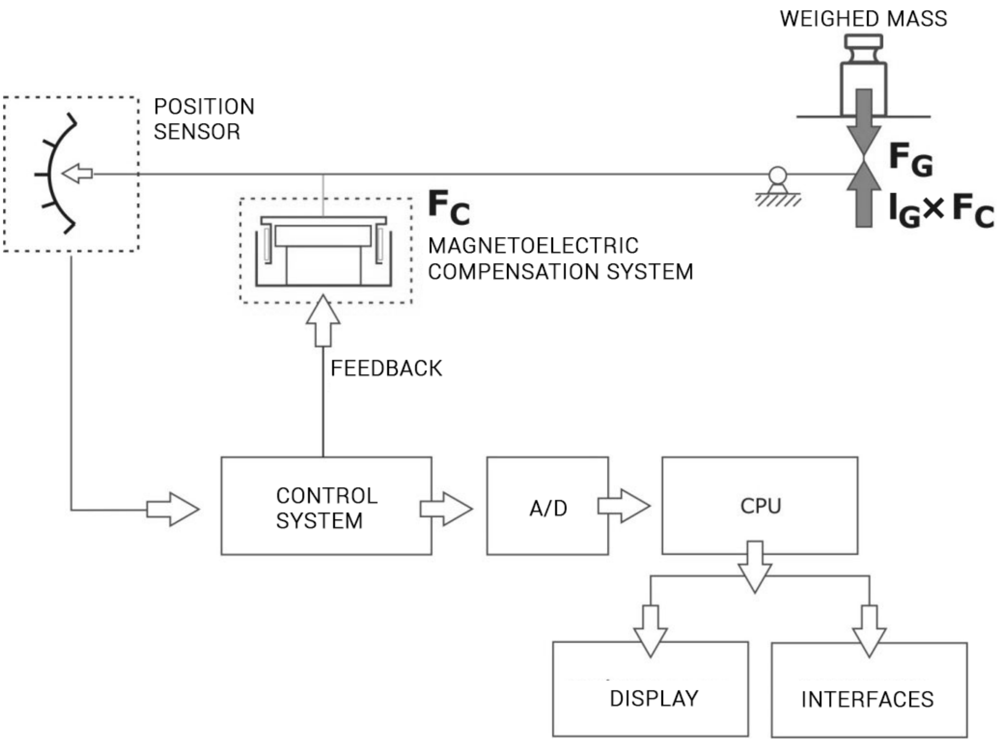


Fig. 20 Diagram of magnetoelectric balance

Electromagnetic weighing mechanism consists of series of connected systems:

- Weighing pan on which mass to be measured is loaded.
- Mechanical system of F_G load transmission from the weighing pan to the solenoid actuator.

- Optical position sensor indicating deflection of the system caused by applied F_G force.
- System for controlling current in coil; the system is coupled with position sensor for compensating applied force and correcting the deflection.
- Analog-to-digital (A/D) converter transforming analog signal of control system feedback to digital value.
- System for processing measuring signal (CPU).
- Optional display and communication interfaces.

Mechanical system for load transmission consists of weighing pan guidance system and lever system of l_G ratio for decreasing load of solenoid actuator's coil installed on longer part of the lever (end one in multilever systems). The system is equipped with elastic, frictionless joint and enables vertical movement of weighing pan and coil in solenoid actuator's body. Position sensor and control system assure that the coil is constantly and fixedly sunk in solenoid actuator's body (symmetrically to the pole shoe).

Applying $F_G = m * g$ force to the weighing pan, where g is gravitational acceleration, causes dislocation of the coil in solenoid actuator's body. Dislocation is detected by position sensor and the information is sent to control system which controls current in the coil in such manner, that the coil takes its original position (the same as when there is no load on the weighing pan).

In this position of the coil, balance between force applied to the weighing pan and force applied to the solenoid actuator's coil is determined in accordance with the following formula:

$$F_G = l_G * F_C$$

Fc compensatory force results from passage of compensatory current through the coil which at the same time is a measuring signal that is processed to digital value.

In balances featuring electromagnetic force compensation, weighing pan deflections (excluding elastic bending of whole mechanism) are minimal, close to zero. Such solution enables achieving high resolutions and small indication errors.

Control system, as required, can operate very fast, therefore achieving lower accuracy but enabling quick measurements. It can also operate slower but with higher accuracy.

In spite of uncomplicated principle of operation, it is hard to obtain correct and precise operation of such systems. It is connected with sophisticated measuring system based on: complex lever mechanism, high-quality magnetoelectric system, precise position control system and analog-to-digital electronics system with advanced technology and software. Errors in design or assembling any of the above function blocks cause malfunction of the whole system. That is the reason why manufacturing of magnetoelectric weighing systems is difficult and expensive. It requires highly professional knowledge on measurements theory, materials science, magnetism and special-purpose manufacturing facility. All factors cause that such equipment is produced only by few manufacturers in the world, including RADWAG.

Difficulties connected with development and manufacturing of magnetoelectric mechanisms are compensated by high resolutions. Currently, the most accurate measuring systems allow to obtain resolutions exceeding value of 20 million with measurement error of few reading units.

Manufacturers of high resolution magnetoelectric converters use pulse-type measuring method instead of A/D converters. In case of such solution, coil is powered with pulse-type current. It enables to remove mechanical defects of balance design and to obtain higher accuracy.

This method does not use monoblock A/D converter, because the coil is operated directly by microprocessor which control signal already contains information on measured mass. This solution is based on developed digital signal processing and requires implementing complex equipment, e.g. digital signal processor (DSP). Such equipment is used in balances of the highest resolutions reaching 100 million reading units.

Magnetoelectric mechanism used in RADWAG APP series of balances is presented below:

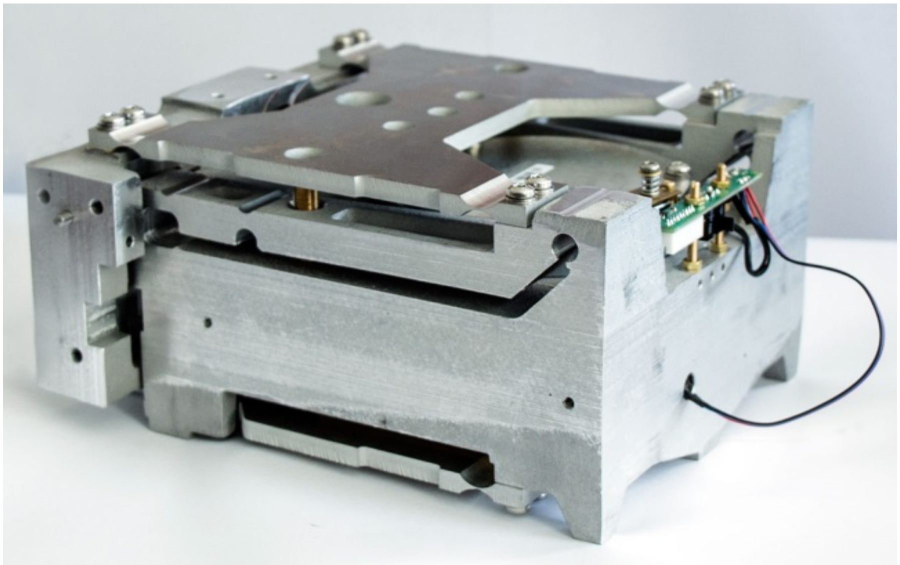


Fig. 21 Magnetoelectric mechanism

Magnetoelectric converters, that are currently manufactured, measure and digitize mass. Obtained digital value of the measurement, depending on the application, is converted to mass value or immediately sent to other control equipment. For this reason, the converters have their own control unit which enables to process measurement signal, to filter and handle communication protocols of other devices.

3.3. Alternative Mass Measurement Sensors

Load cell and magnetoelectric converter presented in the previous chapters are basic weighing equipment that is used worldwide. Nevertheless, it does not mean that there are no other measurement methods. There are devices on the market that use quartz, capacitive and tuning fork sensors. However, they are niche products that can only be used in case of specific working conditions.

3.3.1. Tuning Fork Sensors

Tuning fork sensor is an interesting device for carrying out mass measurement. It is based on tuning fork which vibration frequency increases or decreases depending on the stress to which it is subjected.

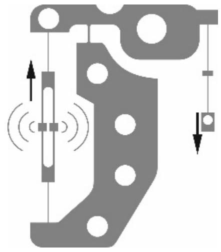


Fig. 22 Tuning fork mechanism

Principle of operation:

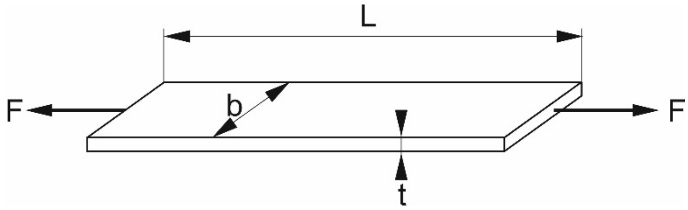


Fig. 23 Vibrating beam

The above figure shows vibrating beam which frequency can be calculated using the following formula:

$$F = A(1 + B \times F)$$

A and B are variables specified by vibrating beam dimensions (L, b and t), material density and Young's modulus. Since vibrating beam is made of metal, it is assumed that its dimensions and density are constant. Young's modulus is also assumed to be constant, due to use of special elastic material which temperature characteristics value is lower than 10ppm/°C. As a result, the frequency of vibrating beam is stable enough to use it as measuring equipment.
Design of vibrating beam reminds of two tuning forks connected together upside down. One part of the sensor is excited with signal from generator and the second generates frequency which depends on applied mass.

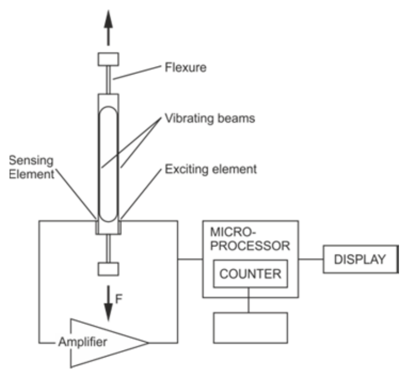


Fig. 24 Diagram of balance equipped with tuning fork sensor

The above simplified diagram shows balance equipped with tuning fork sensor. Such balances are not equipped with A/D converters since data is processed digitally. Microprocessor totalizes impulses from tuning fork sensor and, basing on them, calculates the mass. This is an advantage, since it significantly simplifies its design.

Possible advantages and disadvantages of such solution can be assessed by juxtaposing three sensors: tuning fork, load cell and magnetoelectric.

Feature	Load cell	Magnetoelectric sensor	Tuning fork sensor
Manufacturing cost	Low	High	Higher than cost of load cells manufacturing
Design complexity	Simple	Complex	Complex
Failure frequency	Low	Low	Low
Linearity	Linear dependence between input and output signals	Non-linear dependence between input and output signals	Non-linear dependence between input and output signals
Resolution	Up to 100 000 units	Up to 30 000 000 units	Up to 2 000 000 units
Weighing range	From few grams up to dozens tons	From fractions of milligrams up to several hundred kilograms	From fractions of micrograms up to several hundred kilograms
Popularity	Very high	Very high	Very low

Table 11 - Comparison of weighing modules characteristics

The above table shows that tuning fork sensors have not reached significant popularity, despite many years on the market. They still remain niche products with limited popularity, due to relatively high manufacturing cost and low resolution. Tuning fork sensors operate with resolution of 2 000 000 units. On the one hand, it is an impressive value when comparing them to load cells, but in case of magnetoelectric sensors - it is not. On the other hand, in laboratories tending to maximize measurement accuracy, tuning fork sensors cannot compete with magnetoelectric mechanisms. With their limited resolution, tuning fork sensors are less resistant to ambient conditions than load cells. Therefore, they can only be used to operate under laboratory or mild industrial conditions.

3.3.2. WIM Vehicle Scales Sensors

Continuous development of goods transport by land has significant influence on state of the main and local roadways. Destruction and devastation of roads and bridges increases due to their exploitation by overloaded trucks. Introduced random control systems for vehicles, on which measurements are carried out using stationary truck scales, do not meet the expectations due to their limited capacity. That is the reason of introducing WIM (Weigh in Motion) systems. They are meant to be installed on main roads to monitor vehicles. To fulfil the above aim, development of new measuring sensors for installation in asphalt pavement was crucial. Strain gauges and magnetoelectric sensors cannot be used for such purpose, due to their complicated method of installation in the pavement. Moreover, such solution would be very expensive. On the other hand, change of axle load on asphalt pavement can differ by 40%. For that reason, there is no point in applying precise and expensive measuring sensors. WIM systems use alternative measuring systems of relatively low accuracy. They are designed to be applied in the pavement.

Those sensors are installed perpendicularly to road axle, in this manner enabling vehicle to move through the measuring system. Such action allows to measure actual value of the load of vehicle wheel on the asphalt pavement. For such solutions quartz, capacitive and piezoelectric (polymeric) sensors are used.

Quartz Sensors

Quartz sensor is a piezoelectric sensor placed in aluminium profile of special design. It enhances sensitivity perpendicularly to sensor surface. Such design also reduces shear forces, generated by the vehicle in motion, which contribute to distortions of measuring signal. The system operates by inducing charges on dielectric surface under the influence of mechanical stresses. Sensors are installed in a slot that is cut-out of asphalt pavement, covered with bituminous mass which properties are similar to asphalt parameters. This design does not require using additional elements taking part in transmitting force generated by the vehicle, and decreases its sensitivity to changes in asphalt temperature.

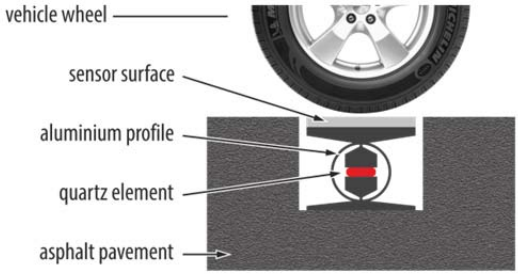


Fig. 25 Quartz sensor design

Sensor advantages:

- at least 10 years of durability,
- wide range of operating temperature (from -50°C to 80°C),
- low temperature sensitivity,
- quick sensor response enabling measurement at 120 km/h,
- good linearity.

The disadvantage of such sensor is relatively high price.

Capacitive Sensors

Capacitive sensor is a kind of flat capacitor. It is a system of two electrodes, isolated from each other with a dielectric, closed in aluminium profile protecting the electrodes from damage and transferring wheel pressure to the sensor. Placing load onto aluminium profile causes its bending and clenching capacitor plates. As a result of clenching the plates, capacity changes. However, this parameter is not used to read mass indication. Sensor connects with the generator which frequency depends on the capacitor volume. The frequency is an output signal for estimating applied mass.

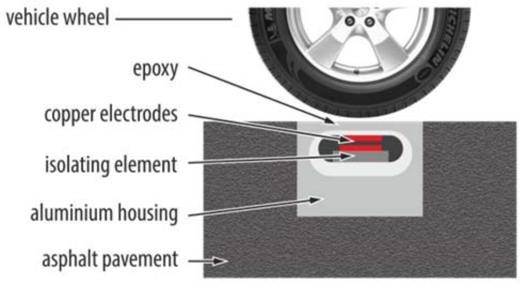


Fig. 26 Capacitive sensor design

The sensors are made as platforms of width up to 500 mm, placed in asphalt pavement, or as small platforms for installing on pavement surface.

Sensor advantages:

- no influence of the lateral forces occurrence,
- possibility to carry out static and dynamic measurements,

➢ good linearity.

Capacitive sensors have the following disadvantages when compared to quartz sensors: narrow range of operating temperature and low mechanical resistance.

Polymeric Sensors

Polymeric piezoelectric sensors, due to low manufacturing cost and high mechanical resistance, are an alternative to quartz and capacitive sensors.
Principle of polymeric sensor operation is similar to quartz one and is based on inducing charges on dielectric surface.

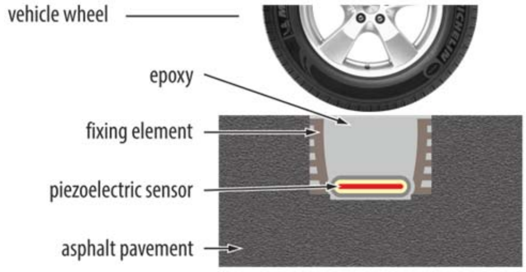


Fig. 27 Polymeric sensor design

Most often, polymeric sensors are flat ribbons or tubes of diameter reaching few to dozens millimetres. They are installed shallowly in few-centimetre deep slots in asphalt pavement and covered with special mass. During operation, sensor has no direct contact with the vehicle. Force is transmitted through the pavement. It causes additional measuring errors. For this reason, system based on such sensors is unsteady and susceptible to changes of pavement parameters under the influence of weather conditions.
Sensor characteristics:

- ➢ high sensitivity to temperature changes,
- ➢ it can only be used for dynamic measurements,
- ➢ high sensitivity to lateral forces,
- ➢ low price.

The above presented sensors are most widely applied in WIM balances systems. Occasionally, such weighing systems using other ways of measurements, e.g. optical fibre sensors. All of the presented solutions enable carrying out measurements of low accuracy and bearing large error. Therefore, they should only be used as equipment for initial mass control. In order to obtain unambiguous results, measurement has to be carried out on stationary balance equipped with load cells.
In addition, possibility to carry out mass measurement is wrongly assigned to inductive sensors used in WIM systems. Such sensors, arranged as induction loop, do not collect information on mass but enable reading so-called magnetic profile of the vehicle. Basing on the magnetic profile, sensor recognizes type of vehicle driving through the measuring workstation and quantity of axles. Those two parameters are crucial for calculating correct mass value of the vehicle.

4. Weighing Modules

In the previous chapters we discussed basic sensors for mass measurement: their possibilities, advantages and disadvantages. However, even the best-selected sensor does not guarantee proper operation of the weighing equipment when signal from mass transducer is incorrectly received, digitized and converted to mass value.
Weighing modules are intermediate elements, located between mass sensor and balance display, terminal or PLC. They are meant to power weighing sensors as well as to collect and convert feedback. The simplest weighing modules can only convert signal from mass sensor to standardised signal in industrial equipment, so most often their output value is 0 – 10V, 0 – 20mA analog signal or the most popular 4 – 20 mA.

Fig. 28 N.B.C. Elettronica analog weighing module

These types of modules do not process sensor signal or feature calibration functions. All functions connected with signal filtering has to be taken over by master unit - PLC in most cases. It burdens PLC with substantial quantity of calculations, thereby decreasing its capacity. A software developer who operates such module has to have knowledge on metrology in order to carry out digital signal processing. The signal is then expressed in mass units. Such equipment cannot be verified and be part of weighing systems in accordance with NAVI and MID directives. All of these inconveniences cause that analog weighing modules are used very rarely and only in simple weighing applications.
For these reasons, digital weighing modules, which functionality is identical as the standard balance, are used most often. Due to their application under industrial conditions, they feature additional functions enabling control over automatic processes.
There are two types of weighing modules on the market:

- strain gauge weighing cell modules,
- magnetoelectric weighing modules.

4.1. Strain Gauge Weighing Cell Modules

Basic and the most commonly used weighing module is designed using load cell. It is due to a fact that load cells are widely applied in industrial processes. Originally, they were directly connected to PLC and used for building autonomous weighing systems. However, due to

complexity of such systems, it was often unsuccessful. Another solution was using standard industrial scales to carry out measurement and send it to PLC or computer. Even though this solution is still common, it is not always effective. Scales are equipped with displays and function keys which, in currently used centralised control systems, enable unauthorized access to the weighing module and changing its settings. It also causes introducing additional control panel to the line, often located in a place that is difficult to reach. What is more, scales are not adapted and properly programmed to be remotely controlled. The solution to all of those problems are weighing modules featuring similar functions as scales. In contrast to the scales, the modules have no displays. Moreover, they enable simultaneous cooperation with few master devices. Thanks to implemented algorithms, weighing modules can carry out dosing and checkweighing processes. At the same time, they can cooperate with PLC, terminals and computers. Integrated input/outputs modules allow to carry out pre-determined manufacturing processes.
Weighing module is equipped with connector dedicated for load cell, analog-to-digital converter system and control processor. It also features communication interfaces which allow to connect external equipment.

Fig. 29 Connection diagram of MW-01 strain gauge weighing cell module

The above diagram presents RADWAG MW-01 weighing module.
Weighing module can cooperate with single load cell or group of load cells which create one weighing system. It can work as a single workstation and/or be a part of control system for weighing process monitoring. Software of MW-01 is designed to operate remotely, without display or function keys. It means that all parameters can be modified with use of communication interfaces. What is more, the module can autonomously carry out pre-determined functions. Such configuration enables to directly send settings and command for running its autonomous operation, e.g. dosing. On the one hand, it allows to free up computing resources of master unit. On the other, improves operating conditions of the process due to elimination of delays connected with current sending of the data.
A common application is the abovementioned dosing. The algorithm of the process is designed as follows: an information on required dosing settings is sent from the control panel or PLC to the weighing module. On confirmation from the module that the setting is accepted, START command is sent using communication protocol or relay inputs. Weighing system starts single or dual stage dosing and sends information on operation status to the controller. Dosing is carried out in accordance with module's internal operation algorithm, assuring quick reaction to mass changes. Therefore, it prevents from overpouring connected with delays in control system reaction to mass increment. On process completion, the

module sends information to the controller to give real values that were dosed. Afterwards, it enters standby mode.
It would be difficult and time-consuming for a user to set all parameters of the module. Due to that, it is possible to use included software intended for the above operation. After that, crucial commands have to be implemented to the PLC.

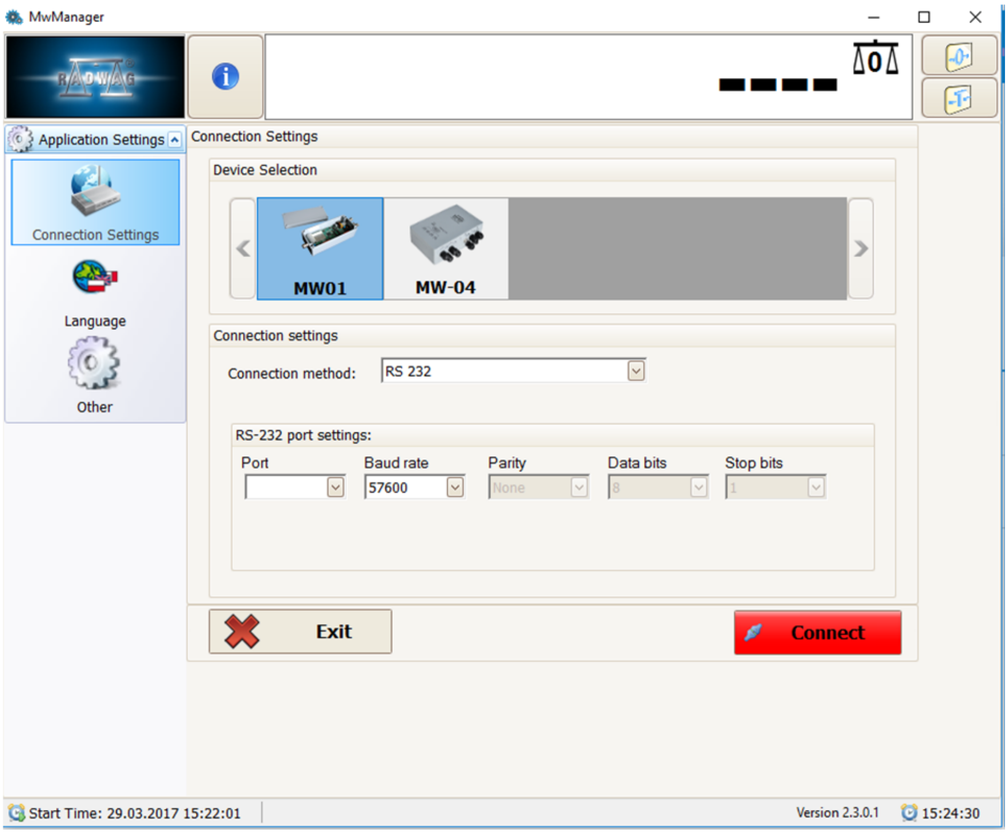


Fig. 30 MW Manager software window

MW Manager is an intuitive software operating on Windows platform. The software allows user to set all parameters of connected weighing module. It automatically detects and communicates with equipment, enables to define all of its metrological parameters and allows to carry out adjustment process. It also makes it possible to run and test special functions connected with automatic processes, such as: dosing, checkweighing, etc.
MW-01 weighing module is a very fast and accurate measuring system, used both for static and dynamic measurements. It has Test Certificate enabling to use it for building certified III class weighing systems of resolutions up to **10 000 verification units.** This confirms high accuracy of the module, since technical limitations of load cells make it impossible to design verified balance with resolution exceeding 6 000e.

Fig. 31 Communication interfaces of MW-01 weighing module

In case of weighing modules, effortless communication with other equipment on the line is crucial. That is the reason why most devices feature built-in interfaces such as: RS 232, RS485, Ethernet and Profibus. Due to their versatility, they can be easily implemented in different types of automatic control applications. The weighing modules can be addressed which, combined with their autonomous operation, enables to connect few of them to one control device. There are also weighing modules allowing for connecting and controlling few weighing platforms independently.

Fig. 32 MW-04 weighing module

An example of such solution is MW-04 weighing module which enables cooperation with four weighing platforms. It is a substitute for four MW-01 weighing modules and offers additional possibilities of automatic operation. It is possible to use MW-04 for dosing or formulation processes which require using four independent weighing platforms of different capacities and accuracies. In such case, formulation containing products assignments to different platforms is sent to the weighing module which starts formulation making process.

On process completion, MW-04 weighing module, similar to MW-01 module, sends information on process completion and obtained sample weights.

While characterizing strain gauge weighing cell modules it is possible to determine their basic features:

- no display,
- compact design,
- wide range of interfaces,
- possibility to operate under hard ambient conditions,
- autonomous operation,
- relatively high resolution,
- cooperation with few weighing platforms,
- possibility to design certified weighing system,
- ease of configuration.

Those main features of strain gauge weighing cell modules contribute to their wide use in industrial control systems, dosing and formulations applications and dynamic mass measurements. Main limitation of the module as a weighing system is cooperation with load cell which does not reach high resolutions required by users. For such applications, it is required to use magnetoelectric weighing module.

4.2. Magnetoelectric Weighing Modules

Principle of operation of magnetoelectric converter - the most accurate weighing sensor on the market - was presented in previous chapters. Laboratory balances and mass comparators - the most precise equipment for mass measurement - are based on this mechanism. Nowadays, it is possible to use magnetoelectric converters for industrial applications. Solutions meeting requirements of electrical and mechanical resistance, required under industrial conditions, were prepared. Mechanisms were strengthened and properly secured from the influence of hard ambient conditions of production line.

Fig. 33 Industrial MWMH magnetoelectric module

Thanks to the magnetoelectric mechanism, the modules kept their basic characteristic - no bending of the measuring system under the influence of applied force. This feature enables achieving very high resolutions with small measurement errors. As it has been proved, this is an advantage as opposed to load cells, in case of which bending is a measure of applied force. Due to that, the resolution is almost one thousand times higher. Next asset of magnetoelectric mechanism is high speed of operation and stability of metrological parameters over time. Magnetoelectric modules are more resistant to temperature and humidity changes when compared to load cells. This is due to temperature compensation to which they are subjected during manufacturing process.

Analog-to-digital converters, used in magnetoelectric modules, digitize the signal with resolution up to 24 bits (16 million units). This determines necessity of carrying out module temperature compensation. It is due to a fact, that temperature coefficients values of mechanical and electronical subassemblies are one or two orders of magnitude higher than permissible error of such precise weighing equipment. Certainly, high resolutions are not required under industrial conditions due to limited accuracy of equipment adjustment. However, implemented temperature correction guarantees very stable operation of the mechanism over time.

Magnetoelectric weighing modules are intended for very accurate mass measurements. It can be said that they are precision and analytical balances adapted for operation under industrial conditions. Their advantage is autonomous operation that does not require connection with the weighing terminal.

Usually, it is possible to use special weighing pan adapted for the requirements of specific application or process. Similarly to strain gauge weighing cell modules, magnetoelectric ones can cooperate with automation systems or machines and devices. They are often components of processing lines and the above equipment.

Capacities and resolutions are the same as for analytical and precision balances. It is possible to carry out measurements with 0.000001g readability. Maximum capacity is usually 64kg and converter divisions range 20 000 000 d.

Magnetoelectric weighing module consists of magnetoelectric mechanism with A/D converter and optional set of communication interfaces, as in the case of strain gauge weighing cell modules.

Fig. 34 MPSH weighing module

Magnetoelectric mechanism used in weighing modules is identical with the mechanism used in typical magnetoelectric balances. The balances use magnetoelectric compensation that very accurately converts mass value to electric signal.

Built-in A/D converter provides digital, filtered information about measured mass. With use of appropriate commands, control device can carry out adjustment, zeroing, taring and other functions.

Fig. 35 Magnetoelectric mechanism used in MAS weighing modules

Fig. 36 Magnetoelectric mechanism used in HRP weighing modules and platforms

As it was mentioned before, magnetoelectric weighing modules feature the same interfaces as strain gauge weighing cell modules: RS 232, RS 485, Ethernet and Profibus. They allow to control the equipment using quick transistor inputs and outputs (I/O). Magnetoelectric modules are equipped with implemented algorithms for autonomous operation. This enables to use them for identical applications as strain gauge weighing cell modules. RADWAG magnetoelectric weighing modules cooperate with MW Manager software, discussed in the previous chapter, that enables their easy configuration.
The modules feature options to connect display and cooperate with terminals, since they are used in processes which require direct mass readout. Due to the abovementioned, they are similar to industrial scales while maintaining all features of the magnetoelectric mechanism.

The most accurate magnetoelectric modules of the highest accuracies feature additional internal automatic adjustment - process of controlling the balance with reference mass - which corrects their work during operation or in case of ambient temperature changes.

Temperature compensation and internal automatic adjustment guarantee measurement accuracy by eliminating influence of the temperature, balance tilting, place of use and passage of time, which presents the graph below:

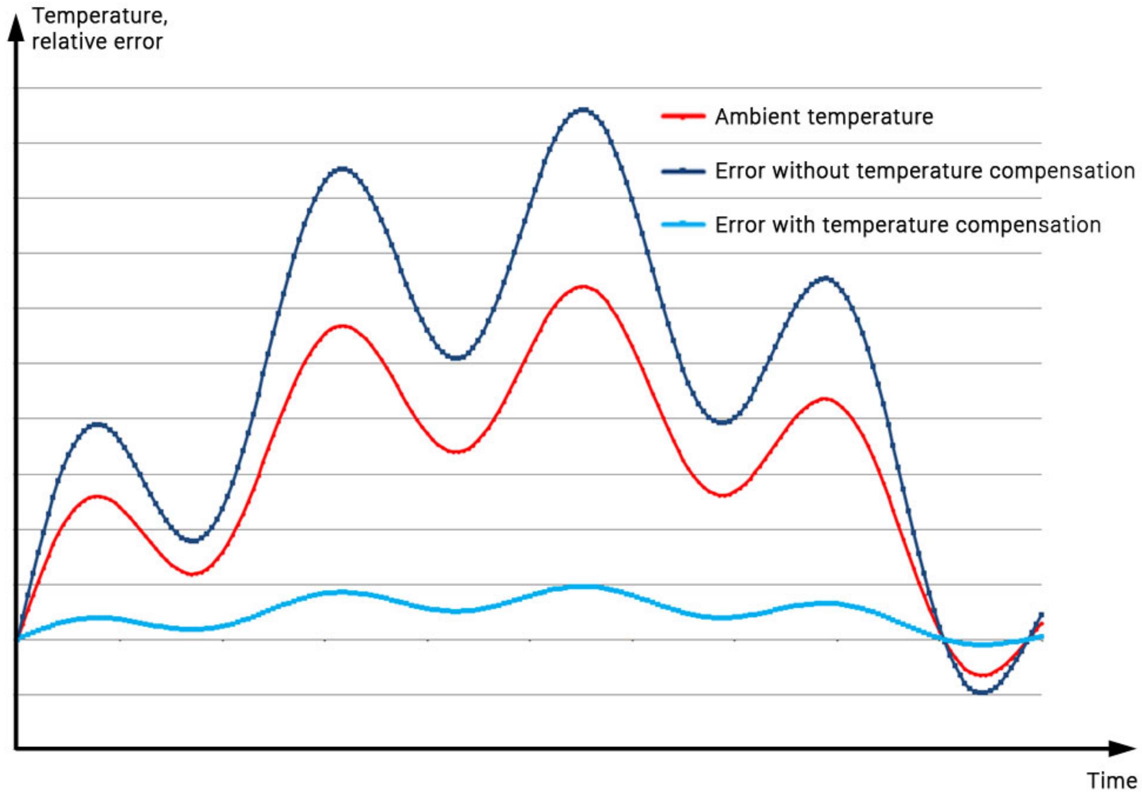


Fig. 37 Explanatory graph showing operation of temperature compensation

Taking into consideration that the weight depends on gravitational acceleration, which differs in various parts of the globe, the indication also depends on the location of balance operation. This potential error is also eliminated by automatic internal adjustment.

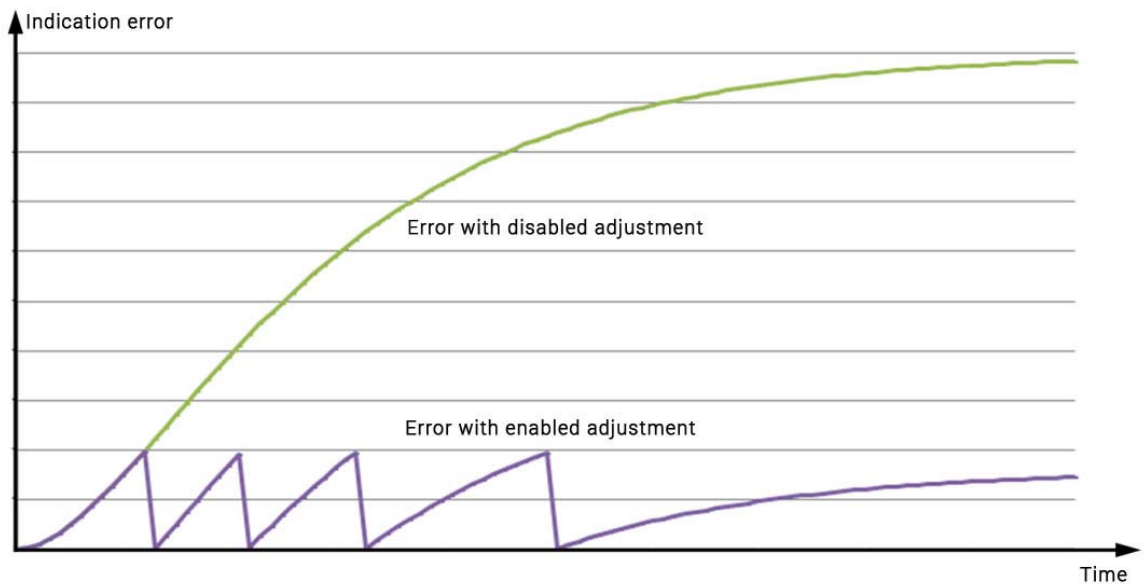


Fig. 38 Graph presenting automatic adjustment process

The above graph (Fig. 38) presents automatic adjustment of weighing module carried out due to changes in temperature during operation. Since weighing modules are equipped with internal adjustment weight and carry out the adjustment process each time they are connected to the mains, also the error connected with variable value of gravitational acceleration is automatically eliminated.

Described adjustment process is carried out by special electromechanical system installed in weighing modules of the highest accuracy. Other types of modules are not equipped with such solution, since errors eliminated using mass standard can only be noticed by balances of 0.001 g readability and higher.
There is no need to use such accurate modules in industrial processes. In most cases, technological process does not allow for unloading the weighing pan and carrying out adjustment, as it is in case of installing magnetoelectric system into other equipment operating in defined cycle or introducing weighing module to the production line.

The photo below presents part of the filling-packing device, for packagings of few kilograms, which operates with frequency exceeding 60 packagings per minute. Weighing module checks mass of packed product over one cycle, which is 1 second long, whereas the process of packaging movement and loading the weighing pan takes about 0.5 s. Therefore, weighing module measures and estimates the packaging in less than 0.5 second. It is a working mode not accessible for standard strain gauge weighing cell modules which stabilize measurement result for much longer. What is more, during operation value of zero indication changes, which makes it necessary to carry out zeroing. Magnetoelectric weighing module operates correctly despite the fact, that it cannot carry out adjustment process.

Fig. 39 Weighing module integrated with packing machine

Another example of magnetoelectric weighing module application is designed and implemented system for weighing car insulating mats. The system is based on RADWAG magnetoelectric MWMH 200 weighing module. Similarly as in case of the example below, the module is an integral part installed inside the packing machine for mats.
The main purpose of the weighing system is to evaluate material quality, basing on its mass, and to send the information to PLC. Magnetoelectric module is used due to large dimensions of the mat (400 x 1600 mm) and low mass of the product, that does not exceed 1500 g. What is more, in order to correctly evaluate material quality, measurements are carried out with 0.1g readability.

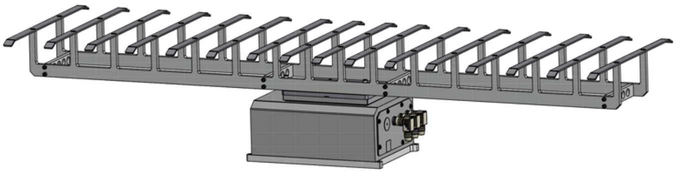


Fig. 40 MWMH weighing module for large products

Only magnetoelectric weighing module can handle with such large element and in the same time maintain stable operation with readability of 20 000 reading units. The weighing module is equipped with measuring platform, designed in a form of grill, that minimizes influence of air drafts and pressure changes over and under the weighing pan. What is more, large mass of the weighing platform is compensated by magnetoelectric system without limiting maximum measuring range. Since mass of weighing platform is 2 kg, in case of strain gauge weighing cell module it is necessary to use sensor of 5 kg capacity. In this case, magnetoelectric module of 2 kg capacity and possibility to compensate mass of the weighing pan up to 6 kg is used.

Magnetoelectric module is applied in a process of weighing graphite powder, applied onto gears, which transforms into synthetic diamond coating.

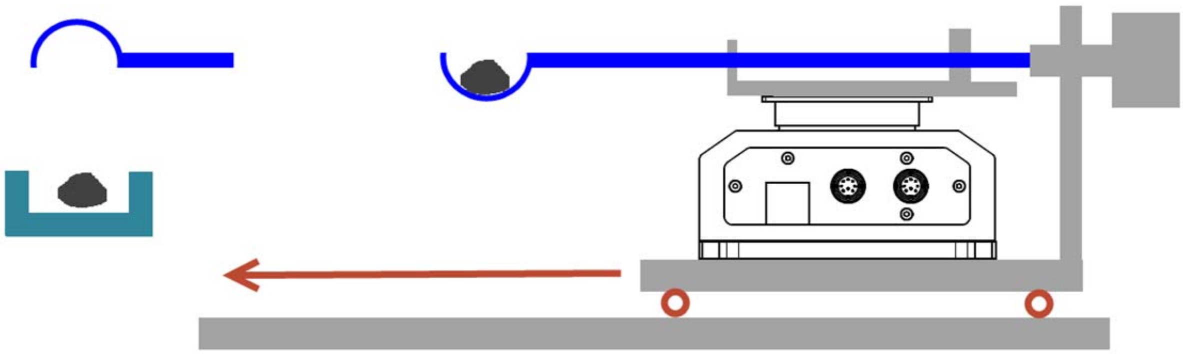


Fig. 41 Dosing system for diamond

Dosing system is designed using MPSH magnetoelectric weighing module installed on a trolley.
Technological process is carried out as follows:
The driver which manages the process communicates with MPSH module using PROFIBUS interface and starts one of few implemented dosing programs. The module dispenses set value (by controlling actuators) and sends information on current mass to the display to be previewed. On dosing completion, the trolley with the module is moved and the dose is poured to the technology vessel. Trolley returns to its initial position and dosing process starts again. At the same time, dosed graphite powder is applied to the product and baked in high pressure chamber. As a result, graphite becomes synthetic diamond. Then, once again, the final product is weighed on a checkweigher. Main requirement of the process is to achieve very precise doses of graphite powder. That is the reason why dosing is carried out

with 0.01g readability using magnetoelectric weighing module.

RADWAG offer contains the discussed weighing modules of different designs and capacities reaching up to 35 kg with d=0.1g readability. Minimum capacity of the modules is 220g with d=0.0001g readability.

Wide range of solutions that differ in capacity, reading unit value, IP rating (IP68 in some of the equipment), type and possibilities of the terminal make magnetoelectric weighing module very attractive and result in fulfilling requirements of most branches of the industry.

They are most widely applied in food, chemical and pharmaceutical industry.

The modules are irreplaceable in Production Control Departments where testing of very precise and expensive subassemblies would not be possible with use of standard, strain gauge weighing cell modules.

As an example, magnetoelectric weighing modules are perfect for controlling of wear of mechanical movable subassemblies such as gear wheels. While carrying out systematic, long-term measurements or comparison with reference mass, it is possible to analyse mass decrement resulting from wear of a particular subassembly. Such analysis is one of the basic tests carried out in control departments of automotive industry.

Magnetoelectric weighing modules are also used as weighing subassemblies in special types of moisture or thermogravimetric analyzers to analyse chemical changes.

In most cases they are used for weighing or determining density of materials of large and unusual dimensions.

To conclude: Wherever application of laboratory balance is impossible due to shape, dimensions, IP rating or lack of communication interfaces, it is possible to use magnetoelectric weighing module.

4.3. Magnetoelectric Weighing Platforms

On the basis of developed industrial magnetoelectric modules, assuring maximum capacities up to dozens kilograms, weighing platforms of maximum capacities up to few tons were designed. Due to that, magnetoelectric mechanisms are now available with measuring range between 0.0001g and few tons.

Weighing platforms equipped with magnetoelectric module are intended for precise measurement of heavy loads of tens, hundreds and thousands kilograms. In terms of measurement, weighing platform is a more accurate equivalent to platform scale. It does not require constant connection with display. Due to the design, it is possible to freely configure type of module for measurement and readout. Since weighing platforms use magnetoelectric module as converter, measuring range is 3t, reading units range 1 000 000 d, while the result is obtained in 1-2 s. Due to high resolution and fast measurement, such solutions replace typical strain gauge weighing cell platforms. They are far more technologically advanced equipment, earning the advantage over strain gauge weighing cell platforms in almost every aspect of measurement process, since they:

- achieve higher resolution,
- carry out faster measurements,

- characterize with higher stability of indications,
- are resistant to any changes in ambient conditions.

Fig. 42 Magnetoelectric weighing platform

Weighing platforms consist of properly modified magnetoelectric module and hybrid lever system which transport the load from the weighing pan. In terms of electronic and software design they do not differ from magnetoelectric modules. They are also equipped with magnetoelectric system, A/D converter and suitable electronic and software solutions providing functionality that is identical to the functionality of typical magnetoelectric modules. Depending on the applications and requirements, they can also be equipped with electromechanical adjustment module.

Used hybrid lever system increases measuring range of the platform. Since typical magnetoelectric mechanisms enable achieving maximum capacity of 100 kg, special designs of lever and gear systems are used to increase this value.

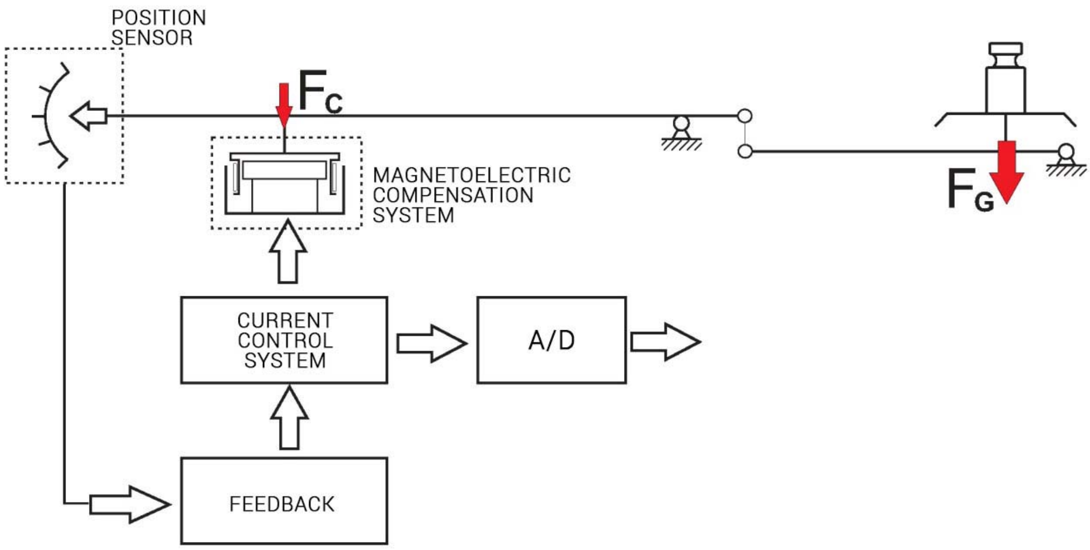


Fig. 43 Diagram of magnetoelectric weighing platform

On the one hand, used hybrid system increases measuring range of the platform. On the other hand, it enables implementing additional protections against overloads. Due to that, the platforms are resistant to overloads reaching 150% of maximum capacity.

As in case of standard magnetoelectric modules, the platforms are subjected to temperature compensation which, combined with adjustment module, guarantees precise measurement while minimizing influence of temperature, place and duration of use.

Fig. 44 HRP weighing platform

RADWAG offers wide range of high capacities HRP magnetoelectric platforms. The platforms are available with maximum capacity of 16kg as well as of 1 tonne.
Solid stainless steel design and high IP67 rating assure precision and extraordinary quality of operation under the hardest industrial conditions (e.g. operation in highly humid environment).
HRP platforms are perfect anywhere high hygiene standards are crucial and obeyed. They operate in food, pharmaceutical and chemical industry where conformity with the highest hygiene standards is required.
Wherever parts counting, formulations, dosing, filling in or mass control is carried out with the highest accuracy - HRP is a perfect choice.
Precise weighing platforms are irreplaceable in warehouses. They are perfect solution, due to large amount of elements, batch quantity and wide range of dimensions, masses and tolerances. Flexibility of platforms types and maximum capacities as well as of terminals with complex software, dedicated for such applications, and possibility to operate in a network and free configuration in the system, enable designing technologically advanced weighing systems.
Versatility of the design and configuration enables building mass comparators - equipment of the highest available measuring resolutions.

Mass comparators feature the same values of maximum capacities as HRP platforms. However, they feature higher resolution, in comparison with standard magnetoelectric platforms, and dedicated software facilitating comparison process of mass standards even for F2 accuracy class. They are used mainly in calibration laboratories, but also in industry: to compare movable mechanical elements that are tested and worn during operation.
Type of used weighing equipment depends on required maximum capacity, resolution, IP rating and communication possibilities.

4.4. Weighing Modules Application

Strain gauge weighing cell modules and magnetoelectric modules are both available on the market. Due to higher cost of magnetoelectric mechanisms, strain gauge weighing cell systems will still be available for purchasing. Both solutions will still be applied due to different types of customers' needs concerning accuracy of the weighing equipment.

The graph below presents fields of application of different types of weighing modules. As it is shown, solutions based on strain gauge enable measurement with readability ranging from 1000 to 100 000 d. In most cases they operate with readability from the middle part of the graph, which is around 3000d, less often 6000d or 10 000d. Measuring range is between 100g to 100 tons.

High resolution magnetoelectric weighing platforms operate with readability ranging from 100 000d to 1000 000d. Maximum capacity differs depending on the type of platform. It may reach 10 kg as well as 3 tonnes.

Weighing modules and magnetoelectric balances have the same fields of application (similar maximum capacities and resolutions).

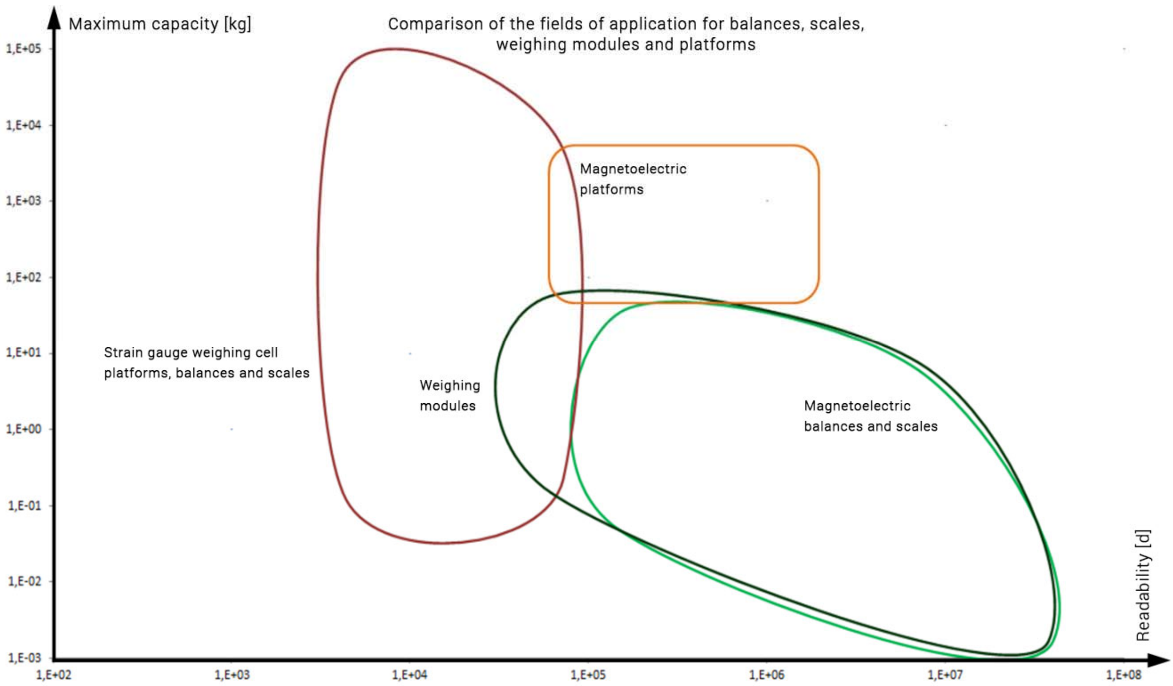


Fig. 45 Comparison of the fields of application for strain gauge weighing cell modules and magnetoelectric modules

Both weighing modules and magnetoelectric platforms combine high resolution, measuring range and IP rating due to their application in industry.

Their common feature is also applying magnetoelectric converter as measuring element.

5. Terminals and Indicators

What is a terminal or an indicator actually?

An indicator or a weighing terminal are commonly known as measuring devices integrated with a display and enabling reading out measuring system indications.

The development of those simple appliances by introducing additional functions, displaying basic text at first, then graphical visualizations, all the way to interactive modules, caused that the primal name stopped reflecting actual functions of the device. Term – weighing terminal was invented.

Fig. 46 HY10 Terminal

Nowadays, weighing terminal is an indicator equipped with analog-to-digital converter and/or adapted to cooperation with digital weighing modules, it also has additional databases and a function enabling communication with the operator at the same time as with the PC system.

The term 'weighing terminal' is truly justified. These are frequently highly specified industrial computers additionally equipped with mass measurement function, but there are also terminals especially dedicated to special processes. Different technical advancement levels of weighing terminals have been presented and characterized below based on RADWAG solutions. Starting from the most basic ones in order to finish with the most specialized weighing computers.

5.1. PUE C31 Indicator

With the creation of the first electronic balance, which operation was based on analog-to-digital signal conversion that was next processed by microcontroller, the first displays were designed. These were digital displays equipped with function keys enabling taring and zeroing of the balance. Due to technological progress and increasing requirements of users, additional functions were added to those simple sensors in order to enable their adaptation in uncomplicated applications.

Fig. 47 PUE C31 indicator with ABS housing

Present-day example of such device is RADWAG-manufactured basic PUE C31 indicator.

Although its functionality is unsophisticated, it is based on modern electric and software solutions ensuring stable and fast operation. Due to easy handling and additional functions, the indicator is very popular. This is a basic equipment applied in medical, postal and warehouse scales. The indicator features RS232 serial connector which enables connection with computer or additional display and printing out measurement result on a connected printer.

Compact housing and battery power supply allow to create mobile weighing workstations

using PUE C31 indicators, e.g. weighing pallet trucks.
High quality and advanced technology of the indicator enable using it in hazardous areas endangered with explosive atmospheres (Ex).
Depending on the application, the indicator features ABS or stainless steel housing (for industrial application).

Fig. 48 PUE C31 hermetic indicator

With use of the indicator, it is possible to design single or dual-range scale with resolution of 6 000 verification units and carry out basic weighing processes due to implemented functions, e.g. conversion of measuring units, parts counting, peak hold and totalizing.

The following tables present technical specifications of PUE C31 indicator and its functionalities.

Operating temperature	-10 ÷ +40 °C
Relative humidity	10÷85% RH without condensation
IP rating	IP 43
Power supply	100 ÷ 240 V AC 50 ÷ 60 Hz / 12 V DC + battery
Battery operating time	35h (average time)
Display	LCD with backlight
Interface	RS 232
Net/gross weight	0.5/0.8 kg
Packaging dimensions	220×190×90 mm
Keypad	microswitch
Multiple range	1 or 2 ranges
Supply voltage on strain gauge	5V DC
Additional display	LCD (an option)
Housing	ABS
Optional power supply	10,5 ÷15V DC Imax = 600mA, and battery
Connection of load cells	4 or 6 wires plus shield
Maximum impedance of load cell	1200 Ω
Minimum impedance of load cell	80 Ω
Minimum voltage per verification unit	1.0 µV
Maximum voltage per verification unit	3.2 µV
Maximum signal gain	19.2 mV
Maximum quantity of A/D converter divisions	838 860 ×10
Keys quantity	5
Maximum quantity of verified units	6000 e
Power supplying method	detachable power supply, NiMH 6×AA batteries

Table 12 - Technical specifications of PUE C31 indicator

Working modes	**Miscellaneous parameters**
Different measuring units: [g], [kg], [N], [ct], [lb]	Measurement result averaging, digital filter,
Autotare, tare memory	Taring in whole measuring range
Totalizing	Battery voltage control,
Counting parts of the same mass	Time-defined finish mode,
+/- control against reference sample mass	Adjusting backlight intensity (during operation on battery power supply),
Percent weighing calculation against reference sample mass	Adjustable serial connector baud rate 200-38400bit/s,
Measurement of maximum force applied on a weighing pan or maximum mass loaded on it,	Continuous transmission of RS 232
Measurement od maximum force applied on a weighing pan (in Newton)	Manual or automatic print out

	Measurement with autozero function disabled
	Possibility to connect additional LCD
	Possibility of printouts customization

Table 13 - Additional functions of PUE C31 indicator

The above listed parameters prove that even basic versions of indicators have to assure wide functionality and possibility of adaptation to different applications. Devices that cannot fulfil users requirements are no longer competitive and they are removed from the market. Only those which functionality and quality are high can still be sold.

5.2. PUE C41 Indicator

Despite modern design and wide range of functions, indicators have one disadvantage - no interaction with an operator. Running individual function is signalled with suitable diodes that are backlit, which is not always clear for an operator. Due to that, indicators featuring alphanumeric keypad and ability to display text information were designed.

Fig. 49 PUE C41 indicator

The above presented indicator features the same functions as terminal. Apart from display, it is equipped with additional text line enabling communication with operator who can enter data using alphanumeric keypad. Keypad design is similar to the one used in mobile phones so it makes interaction between indicator and operator possible. The indicator is equipped with backlit diodes, facilitating operation in dosing mode, uncomplicated database of all settings, weighing records, reports, and base containing operators and products.

The indicator was designed and implemented with a view to weighing workstations that require fast measurement, mainly on dosing stations (e.g. dosing fish to cans), where settings are rarely changed, but measurement speed, damage resistance and simple design are important. It also features implemented software solutions accelerating mass calculation process, so the period of time between loading the weighing pan and obtaining the result is as short as it is possible.

Fig. 50 Production hall, workstations for dosing fish to cans

In addition to display, PUE C41 indicator features three diodes for signalling threshold of the loaded product - whether it is too low, correct or too high. Due to that, operator does not have to read and think about obtained result (whether mass comprises within the thresholds) - it is sufficient to look to the diodes.

The indicator features the following working modes: dosing, formulations, parts counting, labelling, percent weighing, animal weighing - all of this makes it possible to use it for different types of weighing processes. PUE C41 is equipped with more complex communication interfaces than PUE C31 and features I/O system for cooperation with other equipment on production line.

This indicator is the simplest version of weighing terminal with which RADWAG-manufactured weighing equipment is supplied. PUE C 41 has Declaration of Conformity which confirms consistence of the indicator with legal requirements obligatory in Poland and UE.

Its technical specifications are better than technical specifications of PUE C31, since PUE C 41 is designed and intended for operation under industrial conditions.

Operating temperature	-10 ÷ +40 °C
Relative humidity	10÷85% RH without condensation
IP rating	IP 68 (1h max)/69
Power supply	100 ÷ 240 V AC 50 ÷ 60 Hz / + battery
Battery operating time	9 hours (average time)
Display	LCD with backlight
Net/gross weight	3.7/4 kg
Packaging dimensions	320×220×210 mm
Keypad	membrane
OIML class	III
Supply voltage on strain gauge	5V DC
Housing	Stainless steel
Connection of load cells	4 or 6 wires plus shield
Maximum impedance of load cell	1200 Ω
Minimum impedance of load cell	90 Ω

Minimum voltage per verification unit	1.0 µV
Analog outputs module (option)	working mode - 4-20mA, 0-20mA, 0-10V
Ethernet module (option)	consistent with the standard 10/100Mbit/s
I/O module (option)	8 reed relay outputs, 8 opto-isolated inputs
Inputs/outputs (option)	4 opto-isolated inputs, 4 reed relay outputs
Inputs/outputs	3 opto-isolated inputs, 3 reed relay outputs
Opto-isolated interfaces	RS 232, RS 485
Databases	4 MB
Maximum voltage per verification unit	3.3 µV
Relays module (option)	4 relays with a closing contact
Additional weighing platform module (option)	metrological parameters identical with parameters of main platform
Maximum signal gain	19 mV
Maximum quantity of A/D converter divisions	838 860 ×10
Maximum quantity of verified units	6000 e

Table 14 - Technical specifications of PUE C41 indicator

The indicator features all functions of PUE C31 and additional working modes to be used under industrial conditions:

- Single and dual range dosing. The indicator can be used as equipment for dosing and controlling valves installed in the dosing system.
- Preparing mixtures in accordance with formulations. The indicator leads an operator through formulation making process and controls its correctness.

Indicator design is based on modules. This enables development of basic version of PUE C41, depending on the needs, using additional modules increasing its functionality.

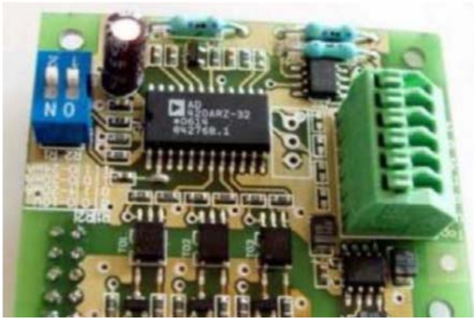


Fig. 51 Analog outputs module

- The indicator can carry out dosing or send mass value using additional analog outputs 0-10V, 4-20mA or 0-20mA.
- It can be equipped with additional I/O module enabling building more complex automatic control systems.
- PUE C41 indicator features possibility to cooperate with second weighing platform. Therefore, in e.g. formulation making processes, it is possible to use two platforms of different capacities and resolutions in order to optimize the process that is currently curried out. Large weights can be measured using large platform, whereas small ones with the use of small platform with higher resolution.
- In case of applying the indicator in systems requiring communication with other equipment using communication interfaces, it is possible to add RS 485 serial connector, e.g. for operating additional display, or Ethernet module assuring connection with computer system.

Very high functional capabilities and durable design of the indicator resulted in creating series of interesting and demanding applications for food and chemical industry. The photo below presents modernised control room in concrete plant where RADWAG-manufactured systems have been installed. Upon modernisation, process of preparing concrete mixes using PUE C41 indicators is completely automatic. Weighing equipment was integrated with systems for dosing of subsequent components. Production process, until now carried out manually using mechanical weighing equipment, was replaced by formulation making processes defined using the indicators. In addition, user can electronically register each component and carried out formulations.

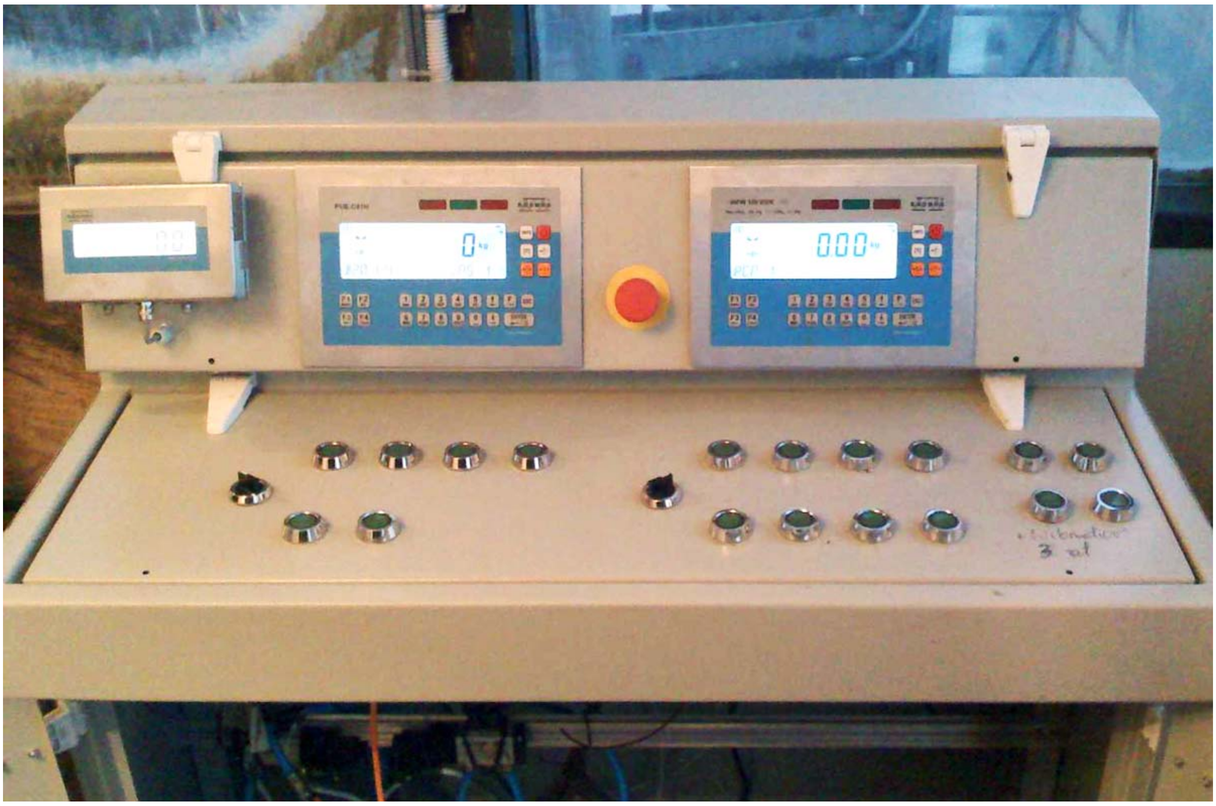


Fig. 52 Control room of concrete plant

Despite the advantages of PUE C41 indicator, it has one significant limitation. PUE C41 is equipped with LCD which displays alphanumeric signs and enables communication with operator. However, the display may be difficult to operate since it is not a touch screen. Therefore it does not meet users requirements. For this reason, successive series of weighing terminals are equipped with more complex control panels providing better communication and preview of carried out processes. Currently, PUE C41 indicator is used in lines for manual weighing, where the most important parameters of the weighing equipment are: measurement speed, design resistance and ease of operation.

Fig. 53 Weighing workstation on fish dosing line

5.3. PUE 7.1/HY Terminals

Fig. 54 PUE 7.1 terminal with stainless steel and ABS housing

Development of LED technology and implementation of devices based on operating systems to the production lines, resulted in designing weighing equipment of new high quality. Indicators featuring large, colour displays were designed to enable graphic presentation of whole range of process data on one screen. Basic numeric mass indicator became part of large information display, giving new meaning to the 'weighing terminal' term.

5.3.1. PUE 7.1 Terminal

RADWAG has introduced very successful series of weighing terminals to the market. These terminals feature PUE 7.1. as their basic part. They are based on Windows CE and equipped with large 5.7" colour display. Due to innovative design and intuitive operation, PUE 7.1. is also applied in laboratory balances.

The main features of PUE 7.1. are:

- relatively large 5.7" display,
- touch screen,
- display customization,

- set of additional function keys,
- two configurable proximity sensors.

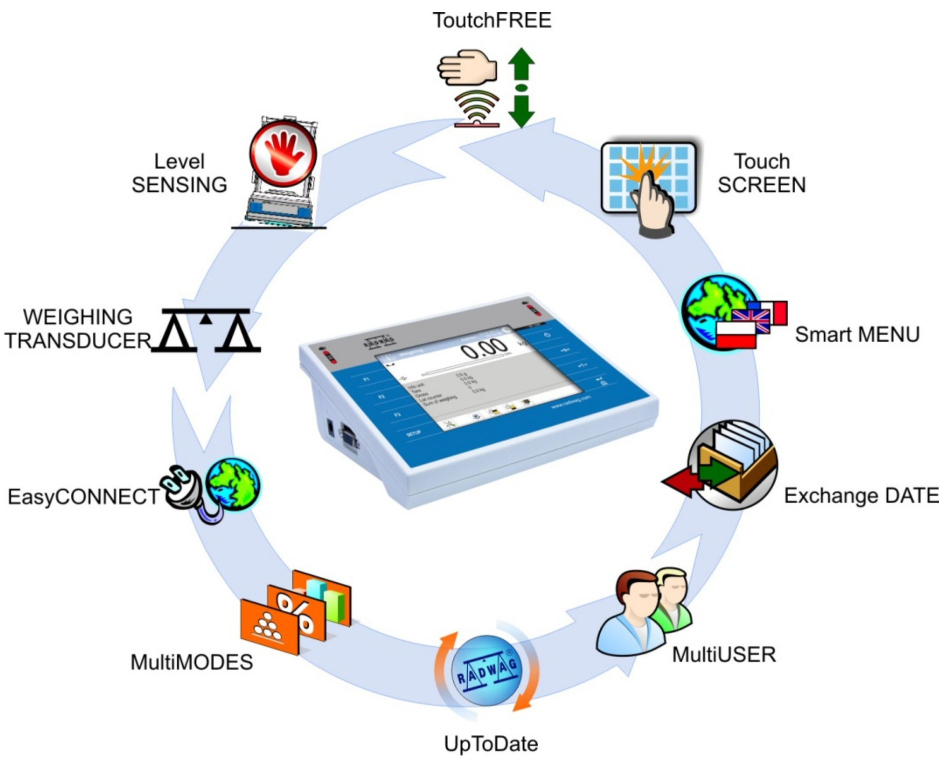
The terminal features two types of housing: ABS or stainless steel for installation in control panel.

PUE 7.1, in contrast with other equipment of similar class, operates on Windows CE7 platform. It allows to create user-friendly and easy to edit environment. Equipment of other manufacturers rarely features operating systems. On the one hand, it makes them cheaper in production. On the other hand, it limits their functionality and possibility to quickly modify software in accordance with customer's requirements. The sign of the times is resignation from RS 485 connector, which was replaced by more efficient and quicker Ethernet and USB interfaces supporting Flash memory, printers and scanners.
A huge advantage of the terminal is wireless network adapter enabling quick and easy access to the network and remote balance-operator connection using computer or smartphone.
The table below contains more detailed technical specifications.

Operating temperature	-10 ÷ +40 °C
Relative humidity	10÷85% RH without condensation
IP rating	IP 43
Power supply	6.5 – 28 VDC
Display	5,7'' (touch screen)
Interface	2×USB, 2×RS 232, Ethernet, 4I/4O (digital), WiFi 2,4GHz b,g,n
Keypad	touch screen
OIML class	III
Supply voltage on strain gauge	5V DC
Housing	ABS
Maximum impedance of load cell	1200 Ω
Minimum impedance of load cell	50 Ω
Minimum voltage per verification unit	0.4 µV
Databases	8 GB (micro SD)
Maximum voltage per verification unit	3.25 µV
Additional weighing platform module (option)	metrological parameters identical with parameters of main platform
Power consumption	21 W
Maximum quantity of operated weighing platforms	2
Operating system	Windows CE 7
Memory	RAM 256 MB
Processor	2×1 GHz
Programmable proximity sensors	2
Maximum signal gain	19,5 mV
Keys quantity	8
Maximum quantity of verified units	6000

Table 15 - Technical specifications of PUE 7.1 terminal

At the same time, terminal internal functions are developed, e.g. algorithms for quick measurement, precise dosing, parts counting, databases systems etc. The terminal can cooperate with load cells, directly connected to its input, and MW-01 modules as well as with magnetoelectric weighing modules.
Intuitive operation and multifunctional software distinguish the terminal among others and enable using it in weighing systems for various applications. To increase its possibilities and functionalities, the terminal is equipped with software for operating printers, scanners and Flash memory to which databases records can be exported during operation on single workstation. The diagram below presents exemplary functionalities of weighing terminal illustrated based on RADWAG PUE 7.



- **Weighing transducer –** (converter type) strain gauge, magnetoelectric, external MW-01 weighing module, magnetoelectric module.
- **TouchSCREEN –** 5.7” colour touch screen.
- **LevelSENSING System –** automatic level control.
- **TouchFREE –** proximity sensors to which program functions can be assigned.
- **SmartMENU –** user-friendly software and intuitive operation, possibility to define displayed data.
- **SelfCAL –** automatic internal adjustment (for laboratory balances).
- **ExchangeDATA –** data transmission using USB connector.
- **MultiUSER –** profiles of users of different permission levels.
- **UpToDATE –** available software update.
- **EasyCONNECT –** Communication interfaces: USB, RS 232, Ethernet, I/O.
- **MultiMODES –** wide range of functions and applications: parts counting, dosing, statistics, pre-packaged goods control in accordance with the Act, formulations, labelling.

5.3.2. PUE HY Terminal

PUE 7.1 terminal is a base to next versions of PUE series. Terminal offered at the same time as PUE 7.1. is HY intended for industrial applications. HY is designed to operate under hard industrial conditions. It is possible to use external alphanumeric QWERTY keyboard that enables terminal operation in gloves commonly used on production lines. At the same time, all functions of PUE 7.1. terminal are kept (except for proximity sensors that do not operate correctly under harsh ambient conditions, e.g. dust, humidity).

Fig. 55 HY weighing terminal

The terminal features additional I/O modules and supports 0-10V, 4 – 20 mA and 0-20 mA analog outputs. Four weighing platforms, external keyboard and mouse can be connected to HY terminal.
Due to industrial application, the housing provides IP68/69. RS 485 communication interface has been restored due to its use under industrial conditions. At the same time new communication standards have been assured by implementing operation of PROFIBUS DP module. The terminal, in basic option, offers control of 3 transistor outputs and 3 transistor inputs and gives possibility of development to 8 reed relay inputs and 8 reed relay outputs.
The table below contains more detailed technical specifications:

Operating temperature	-10 ÷ 40 °C
Relative humidity	10÷85% RH without condensation
IP rating	IP 68 (1h max)/69
Power supply	100 ÷ 240 V AC 50 ÷ 60 Hz
Display	5,7'' (touch screen)
Net/gross weight	4.5/5.5 kg
OIML class	III
Multiple range	RIGHT
Supply voltage on strain gauge	5V DC
Housing	Stainless steel
Optional power supply	10 ÷ 24V DC
Connection of load cells	4 or 6 wires plus shield
Maximum impedance of load cell	1200 Ω

Minimum impedance of load cell	80 Ω
Minimum voltage per verification unit	0.5 µV
Serial interfaces (option)	RS485, RS232 modules
Profibus module (option)	PROFIBUS DP
External keys PRINT, TARE	YES
ETHERNET interface	Socket
USB interface	Socket
AN xxx module (option)	Current loop 4-20mA, 0-20mA, looped-in voltage 0-10V
4I/4O module	4I (opto-isolated inputs of 5 - 24V DC input voltage) 4O (NO reed relays of 50V DC 0.2A reed load)
8I/8O module	8I (opto-isolated inputs of 5 - 24V DC input voltage) 8O (NO reed relays of 50V DC 0.2A reed load)
RS232 interface	2×Socket
Inputs/outputs	3 I / 3 O - Socket
Maximum voltage per verification unit	3.25 µV
Maximum quantity of operated weighing platforms	4
Operating system	Windows CE 6.0
Memory	RAM 64 MB, Flash 1 GB
Processor	ARM 200 MHz
Maximum signal gain	19,5 mV
Maximum quantity of A/D converter divisions	838 860 ×10
Maximum quantity of verified units	6000 e

Table 16 - Technical specifications of PUE HY terminal

Special functions and different working modes have been optimized in terms of functionality, speed and quality of operation. Self-learning and corrective functions as well as vast number of algorithms were implemented to control correctness of processes realization. In case of dosing, the terminal checks obtained readability and implements crucial corrections. In parts counting mode HY can correct reference mass in order to calculate the parts more accurately.

The table below contains set of most important functions and working modes.

	Dosing	Mode enabling carrying out automatic dosing process.
	Labelling	Mode enabling balance - label printer cooperation. It is a complex working mode, assuring customization of the labels, printing out labels for one product, labels for group of products (cumulative label - C label) and labels for group of C labels.
	+/- Control	Mode operating on a similar principle as checkweighing function in PUE C41 indicator. Checkweighing process is represented by a bar graph correcting process readability.

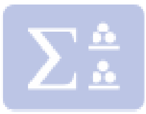
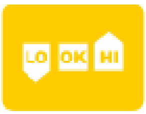
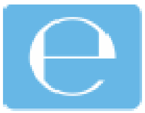
	Percent Weighing	Mode for comparing mass of weighed loads with reference mass.
	Totalizing	Mode for totalizing individual weighing results.
	Parts Counting	Mode using mass measurement to calculate parts quantity.
	Formulations	Mode for carrying out formulations. Function is supported by indicators and bar graphs facilitating process realization.
	Statistics	Mode for archiving weighings and generating reports.
	Animal Weighing	Mode facilitating weighing of animals that move on the weighing pan.
	Pre-packaged Goods Control	Mode for carrying out pre-packaged goods control in accordance with valid Act.

Table 17 - Special functions of PUE HY terminal

HY terminal is used in different types of technological processes which are unique and depend on customer requirements that cannot be predicted during terminal programming. That is the reason why function for individual design of device operation algorithm was implemented similarly to industrial PLC. Such functionality was implemented in terms of designing individual dosing systems and working modes: weighing, parts counting and percent weighing.

In case of dosing processes, user can define individual operation algorithm by setting functions of terminal inputs and outputs and creating the realization cycle. Dosing can be carried out on few weighing platforms automatically or half-automatically and half-manually. It means that part of the ingredients can be added manually. The process can be associated with other equipment operating on the line and depend on it, e.g. carrying out subsequent stages of dosing can be connected with operation of other equipment and realization of algorithm by another device.

During weighing on a production hall, errors caused by human factor, e.g. incorrectly carried out weighing process, are frequent. Even the simplest weighing process can be burdened with error, e.g. when operator selects wrong product from the database and measurement defined as A product instead of B product is send to the computer.

In order to avoid such errors, HY terminal features function for traceability process. This function enables programming and controlling all steps of the weighing process with use of terminal. Defining particular components of the traceability process is similar to defining formulation. Balance administrator can determine whole weighing process with use of available commands. Weighing process may look as follows:

1. Balance operator logging-in using proximity card.
2. On logging-in, message for entering number of work shift is displayed.
3. Zeroing is carried out.
4. Message and series of commands 'Prepare product for weighing' are displayed.
5. 'Scan product label'.
6. 'Specify current product price'.
7. 'Select country' (out of list).
8. 'Select customer code' (out of list).
9. 'Specify lot no.'.
10. 'Specify batch no.'.
11. At the end, message 'Start weighing process' is displayed and terminal enables saving the measurement.

Exemplary process can be modified and new parameters can be add depending on user requirements. It can also be connected with other control system using I/O module.

Fig. 56 Checkweighing system

Multifunctionality of the terminal and easiness of its adaptation to different applications have contributed to its popularization and use in industrial systems. Photos below present examples of control systems using HY terminals.

Weighing system presented on the photo was designed to carry out ingredients checkweighing.

Panel version of HY terminal was installed in control panel. Large industrial buttons were installed on it and connected to terminal inputs. With use of buttons, product can be selected and dosing process started. Large buttons enable carrying processes in thick gloves which are used by employees on the production line.

Fig. 57 Dosing system

The photo presents workstation using PUE 7.1. terminal for filling up big bags. Two terminals showed on the photo are connected to the computer system which sends dosing settings to them. Dosing process uses digital outputs of the terminal - dispenser is activated. On reaching pre-determined mass, dispensers are deactivated. Acoustic-optical signalling device signals process completion, measurement result is saved to balance memory and sent to computer system.

Fig. 58 WLY scale

Systems of industrial scales are not only processing devices. Weighing terminals are very often used in control and monitoring processes. The photo presents WLY scales, equipped with PUE 7.1. terminal, intended for carrying out pre-packaged goods control in accordance with the Act. Terminal software features PGC working mode in which all requirements of the Act are concluded. It enables to carry out control and generate necessary report. Operator is guided by the software and his activities are limited to executing commands.

5.3.3. PUE HY10 Terminal

Currently, the latest weighing terminal of PUE 7.1/HY series is PUE HY10. Its design is a continuation of industrial PUE HY terminal design.

Fig. 59 HY10 Terminal

The terminal features identical functions as PUE HY. 5.7" display was replaced by 10.1" wide screen. External keyboard was changed to an on-screen keyboard. It did not limited possibility to operate the terminal with gloves. Special version of touch screen reacts to bare hand as well as to hand in rubber or wool gloves.

Additionally, quantity of operated platforms is developed from four to six. Also computing power of the terminal increased using more powerful processor.

The table below contains more detailed technical specifications.

Operating temperature	-10 ÷ +40 °C
Relative humidity	10÷85% RH without condensation
IP rating	IP 68 (1h max)/69
Power supply	100 ÷ 240 V AC 50 ÷ 60 Hz
Display	10.1" colour widescreen 1024x600
Touch screen	capacitive
Keypad	touch screen
OIML class	III
Supply voltage on strain gauge	5V DC
Housing	Stainless steel
USB	2 connectors
RS 232	×1
Connection of load cells	4 or 6 wires plus shield
Maximum impedance of load cell	1200 Ω
Minimum impedance of load cell	50 Ω
Minimum voltage per verification unit	0.4 µV
Ethernet	×1
Analog outputs module (option)	working mode - 4-20mA, 0-20mA, 0-10V
Maximum voltage per verification unit	3.25 µV
Maximum quantity of operated weighing platforms	6 (2 x internal weighing module + 4 x external weighing modules)
Operating system	Microsoft Windows Embedded Compact 7
Memory	RAM 256 MB DDR2, 8GB - microSD
Processor	2×1 GHz
Maximum signal gain	19,5 mV
Maximum quantity of verified units	6000

Table 18 - Technical specifications of PUE HY terminal

An easy to notice innovation is a display divided into four independent parts that can be customized or connected together to achieve large diagram containing measurements or masses.

The photo below shows exemplary configuration of main terminal home screen with keys for quick selection of the product.

Table 19 - PUE HY10 terminal home screen

PUE HY10 software can be used to design stations for labelling, parts counting, formulations, pre-packaged goods controls, dosing and vehicle scales. With all those working modes, the terminal can operate individually on a single stand or carry out interactive connection with computer system. What is more, in case of any problems with connection during network operation, the terminal automatically switches to single stand operation and saves measurement to its memory. On restoring connection with computer database, the terminal updates data and returns to network operation. HY 10 features new ways of scale adjustment: 'Virtual calibration' and 'Adjustment with pan loaded'. The first option enables adjustment without use of mass standards. Adjustment is carried out using factory coefficients for load cells which are to be found on load cells data sheets and are provided by their manufacturers. Basing on the coefficients, terminal algorithm calculates adjustment factor.

'Adjustment with pan loaded' enables to carry out adjustment process one more time with loaded weighing pan, e.g. in case of silos. A complement to PUE HY 10 software are communication interfaces that allow to connect printers, scanners, USB flash drives, external industrial buttons to the terminal and enable establishing its communication with computer.

Implemented Modbus RTU protocol, Profibus interface support and complex I/O module featuring 12 inputs and 12 outputs prove that PUE HY 10 is a typical industrial terminal.

5.4. PUE 5 Terminal

Fig. 60 PUE 5.15; PUE 5.17 terminal

Currently, among all types of weighing terminals designed by different manufacturers, the most advanced solutions in technology and functions were based on industrial computers, Windows Embedded operating systems and 12" touch screens.
It should be noted, that such solutions are designed only by few manufacturers of weighing systems. Such equipment is intended for operation in locations of high humidity. This feature distinguishes them from standard industrial terminals that are to be installed as part of a panel, e.g. control panel.
One of the most important problems in case of such equipment is combining abstraction of heat, generated by industrial computer, with tightness - presented terminals feature special design that solves this problem. Due to the above, it is possible to operate them under high humidity conditions.
There are two reasons for using large displays and industrial computer in terminals: on the one hand, it enables to create easy-to-use and intuitive interface for designing advanced weighing systems. On the other hand, it is a completed equipment for customers designing their own visualization systems.
In the second case, the terminals are equipped with Windows system and *.dll dynamic-link libraries enabling communication with weighing module. Potential customers can buy verified weighing equipment and load their own applications.
In dosing and formulations system, they enable using many weighing platforms and simultaneously carry out dosing with full control of the process. Standard terminals cannot perform the abovementioned actions.

Currently, weighing terminals are used to design single station and multitasking weighing systems cooperating with central IT database system. Due to great amount of data sent (measurement records, products and operators databases, etc.), Ethernet is a basic communication interface. In most cases, the terminals software enables setting standard TCP/IP parameters. Therefore, the terminals can operate in industrial systems of freely configured network. Weighing terminals operate in 100Base-TX standard (up to 100Mb/s) for which maximum length of the segment is 110 m with unshielded twisted pair cable.

RADWAG offers two types of weighing terminals that feature different screen sizes. PUE 5.15 terminal is equipped with 15.6” screen of 4:3 aspect ratio and the second terminal features 19” widescreen of 16:9 aspect ratio.

The table below contains detailed technical specifications for both terminals.

Operating temperature	0 ÷ 40 °C
Relative humidity	10÷85% RH without condensation
IP rating	IP 67 - version with infrared controlled panel/ IP 68 - version with resistive touch panel
Power supply	100 ÷ 240 V AC 50 ÷ 60 Hz
Display	LCD 15.6" (touch screen) / LCD 19" (touch screen
Touch screen	infrared controlled panel (standard) or resistive touch panel (option)
Net/gross weight	10.5/11.5 kg; 14/15 kg
Packaging dimensions	560×360×240 mm; 590×430×240 mm
OIML class	III
Supply voltage on strain gauge	5V DC
Housing	Stainless steel
Connection of load cells	4 or 6 wires plus shield
Maximum impedance of load cell	1200 Ω
Minimum impedance of load cell	80 Ω
Minimum voltage per verification unit	0.4 µV
USB interface	4 x USB 2.0 (2 × USB A, 2 × M12 4P)
Serial interface	2 x RS 232 (*), 1 x RS 485 (2 × M12 8P)
Profibus DP interface	operation mode: slave
External buttons PRINT, TARA, START (option)	terminal version with 4I/4O (M12 8P ports) installed
Ethernet	2 × 10/100/1000 Mbit
Inputs/outputs (option)	4I/4O (2 × ports M12 8P or 2× cables fed through the cable gland)
Maximum voltage per verification unit	3.25 µV
Additional weighing platform module (option)	additional max. 3 pcs (metrological parameters as in the main weighing platform)
Data memory	SSD 60 GB
Chipset	Intel® HD Graphics Gen 7
Power consumption	50 W
Operating system	Microsoft Windows 7 Embedded
Memory	4GB DDR3L 1333MHz max 8GB
Processor	Intel® Celeron® 2GHz Quad-core 2MB cache
Maximum signal gain	19,5 mV
Maximum quantity of A/D converter divisions	838 860 ×10
Maximum quantity of verified units	6000 e

Table 20 - Technical specifications of PUE 5 terminals

PUE 5 series terminals can be connected with four strain gauge weighing cell platforms at the same time due to use of MW-04 weighing module. It is also possible to connect RADWAG-manufactured high resolution laboratory balance and weighing modules using communication interfaces. With such flexibility in hardware and software settings, the terminal can be used both on production line and laboratory workstation. PUE 5 terminal features series of communication interfaces that can be used at the same time providing communication with both computer system and weighing module.

The photo below presents PUE 5.15 terminal with implemented visualization system for syrup dosing, which is connected with additional system for controlling material temperature.

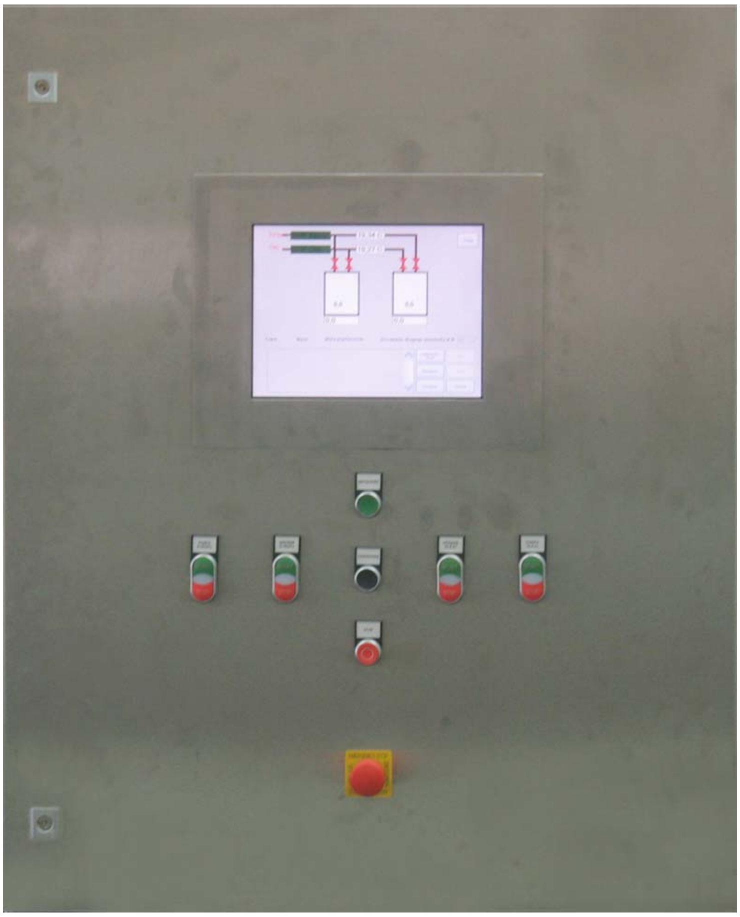


Fig. 61 PUE 5.15 terminal with visualization software

Another example is PUE 5.15 terminal installed in meat establishment and connected with computer system. Commands for an employee are directly sent from computer system and displayed on the terminal. All operations carried out by operator are directly sent to master unit and registered in it. Terminal software was supplied by external company by order of the meat establishment. RADWAG provided weighing platform and terminal that enable running customer's application.

Fig. 62 PUE 5.15 terminal in meat establishment

In conclusion, industrial weighing terminals can be characterized as multifunctional weighing indicators assuring easy and user-friendly interaction with operator. Their functionality often exceeds problems connected with mass measurement and allows to use them in completely different fields of industrial automation. PUE 5 terminals do not have to be connected to weighing platform. Their functions depend on type of application that is to be designed on their basis.

Weighing terminals are intended for operation under hard industrial conditions. They can carry out complex processes autonomously or, connected with computer control system, being its peripheral communication terminals. Interfaces enable sending additional process data to the computer. The data is collected from other equipment, such as: readers, scanners, sensors and many others.

6. Weighing Systems Operating on the Basis of Non-automatic Scales

Digitalisation, omnipresent in every single area of life, for obvious reasons is also a key issue when it comes to balances and scales. Nowadays almost all manufacturers own more or less advanced weighing system in their factories. Among the most basic weighing solutions there are either unsophisticated scales connected with external barcode scanners or signalling device, or balances equipped with simple communication interface facilitating intuitive communication with the device. Although the said systems serve their primary purposes well, they do not meet growing demands of the users.

Need for constant optimisation and control of the production has resulted with the necessity to store vast amount of data sent by various kinds of sensors, probes, scanners, indicators and last but not least, by weighing instruments. For most manufacturers the weighing instruments are basic source of information about manufactured package weight, they not only warn that a given product is out-of-tolerance but also control the whole packing process. Due to this functionality, the simple weighing devices featuring small displays that provided only weight value have developed into advanced terminals guiding the operator through various processes. Present weighing systems operating on the basis of industrial computers facilitate performance of much more complex processes than just simple weighing therefore they can be compared to industrial terminals cooperating with visualisation systems.

Constant need for growth of productivity and attempt to reduce loss motivate the weighing instruments manufacturers to develop their products and care for improvement of the quality, accuracy, reliability and most of all speed increase.

6.1. Counting Systems

Weighing systems designed to count pieces on the basis of reference weight value, are commonly known and applied wherever massive quantities of alike products are packed, i.e. in factories, stores, warehouses and shops offering metallurgical products. Counting systems are generally used in furniture, pharmaceutical and food industry, and also in packaging of electronic and electrical systems. One crucial condition allowing to introduce the counting system is the necessity to maintain repeatable weight of measured elements.

At the very beginning, the parts counting function was just an additional module boosting functionality of either industrial scale or laboratory balance.

In order to run this function it was necessary to carry out process of determination of reference weight, which was done on the basis of reference sample. As for calibration method, it remains the same until now. The operator declares reference sample quantity and on the basis of introduced data the scale determines single part weight.

$$\frac{Loaded\ parts\ weight}{declared\ quantity} = single\ part\ weight$$

Needless to say, such operation is automatic from the start to the end, the result is recorded to scale's memory. With single part weight determined the operator can finally start the counting process. It is obvious that function correctness depends on how accurately single piece weight value has been determined. This shows that the first stage, single piece weight determination, is an extremely important part of the counting process. Counting function correctness is also influenced by repeatability of weight of particular pieces of the given element.

In case of metal products industry where there are so many various products, often about 10 000 different elements, previous solution requiring calibration to be carried out each time was quite tedious and uncomfortable, it often led to errors in counting which was an effect of inappropriate selection of reference sample. Lack of function such as label or receipt printing was another drawback.
Current solutions based on weighing terminals eliminate all the previous problems and inconvenience. The counting system is no longer an individual workstation but a set of cooperating devices.

Fig. 63 Counting set

The above presented set comprises:

- scale operating on the basis of PUE 7 terminal,
- PS precision balance, functioning as additional platform used for precise calculation of reference weight,
- label printer,
- barcode scanner (not presented in the photo).

The presented system is a stand-alone set performing parts counting operation. The PUE 7 terminal has been equipped with database system featuring:

- large products database,
- customers database,
- operators database,

- reports database,
- labels database, and database with records of components, packaging, warehouses, weighings and universal variables.

Basic functionality of the device allows to:
- identify operator carrying out the weighing operation,
- select element for counting witch is done using the barcode scanner,
- design and edit labels,
- print labels, C labels (cumulative labels) and CC labels (cumulative label for C label),
- determine single piece weight using PS Precision balance.

If the reference sample mass is a constant value which is known to the operator then the process of determining it can be omitted. The terminals enable operator to enter the known value directly using the balance keypad. By means of PUE 7.1 software the user can assign determined reference sample mass to a particular product form a database. With this, counting of particular product selected form a database may be carried out without the necessity to determine reference sample mass.
Reference sample mass can be obtained:
- by determination with use of the counting balance,
- by determination with use of a precision balance of higher accuracy,
- manually by entering the exact value of reference sample mass,
- by selection of database stored product with assigned reference sample mass value.

Basic functionality of single labelling workstation can be boosted by connecting it to the central computer with databases. Upon such connection databases of all balances and scales cooperating in a system get automatically interrelated. If for any of the balances settings or databases change then the system automatically carries out update of remaining balances data. Any operations performed by the balances are immediately recorded into a computer system, with this monitoring and managing teams can preview the whole process flow.

Mass of single reference sample is determined in parts counting process using mathematical formulas and it is independent form scale interval. Due to this the parts can be counted with greater accuracy than the scale interval allows. In order to obtain demanded accuracy in parts counting process it is necessary to respectively select resolution and weighing range with reference to counted batches and mass of single pieces, wherein it must be remembered that mass of single piece cannot be lower than 0.1 of scale interval. It is a fundamental condition. The value of reference sample mass does not have to be determined through weighing. It may be a digit value taken form a completely different source (e.g. certificate, quality system, scale or balance of a different resolution). This kind of approach is often used in so called two-platform systems. Two-platform systems comprise one platform of quite high resolution and one with high capacity. Such solution allows correct counting of parts of low weight per unit and also parts of heavy total mass.

Manufactured or reproducible elements always vary in terms of mass (although they seem to be identical, e.g. coins of the same nominals or alike nuts) and only detailed mass control, carried out using scales of particular accuracy shows the differences. The following question arises:

What can be done in order to determine precise weight of a single piece?

A solution to this problem might be determination of mass of single piece taken from sample comprising e.g. 50 or 100 alike elements. Since determined mass is an average value of large batch therefore probability that all parts have been counted correctly is very high. Unfortunately this solution requires manual counting of large number of pieces at the first stage, for this both absolute precision and conscientiousness are necessary. When there is a need to determine reference sample mass for numerous products then manual counting becomes a kind of challenge and a problematic issue.
With reference to the above, RADWAG counting instruments have been equipped with automatic function of correction of accuracy. This function aims to modify weight value of a single part in the course of automatically carried out counting. Therefore it is possible to determine mass of a single piece out of 10-piece set and next to correct it gradually - it is calculated with reference to greater sample, which sample is formed by adding new pieces to it. Even insignificant increase of amount of pieces on the weighing pan results with automatic taking of the new single mass value on (calculated on the basis of greater sample) for calculation.
Such solution improves reliability and accuracy of the counting set.

6.2. Labelling Systems

Over the last few years, labelling systems have transformed as much as the already mentioned counting systems.
Primary labelling systems were designed on the basis of standard industrial scales equipped with RS 232 interface and cooperating with receipt printers. Considerable cost of labels and printing instruments acted against advancement of this group of industrial scales. Along with the first malls and with the development of transport and logistics a greater interest in this kind of solutions was noticed among manufacturers and distributors.
Producers designing industrial scales started to develop the software intended for receipt printers in a way enabling their cooperation with labelling instruments. Years ago a label template was designed using a computer program and next it was loaded into a labeller which required the labeller to be brought from the production line to the office. At that time scale functioned as a device sending weight value to the label, unfortunately it was impossible to avoid numerous problems, i.e. errors in programming a label or errors concerning printout on a scale. Engineers programming software for labelling devices often reserved too little space for a variable sent from the weighing instrument (weight value). In consequence the operator faced either lack of printout or printout of an empty label. Such situation required the whole programming procedure to be performed from scratch -

starting from the designing stage, through bringing the labeller to the office, loading the label into it and taking it back to the production line, to finally test its operation.
The next development stage, when it comes to labelling systems, was introduction of text variables that could be printed on the label. This simplified operation of labelling system a little bit. Such data as ingredients list, expiry date, name etc. could be edited and slightly modified using the weighing terminal.
In present weighing terminals featuring wide memory space and advanced CPUs (Central Processing Units), the programming method and operation of labelling systems have been modified. Prior start-up the user has to design label template, which template is next loaded into the terminal via Ethernet, RS 232 interface or with use of USB flash drive. Next, using the weighing terminal, a particular label is assigned to a given product recorded in the balance-stored database. The user can assign a product with a completely different template at any time. He, or she, can also redesign the template and thus change label for all products to which it has been assigned. Modern labeller stores only respective fonts and set of necessary images printed on the labels, therefore there is no need to interfere into its memory which significantly simplifies operation of the labelling system.
Connecting the scale to a computer network simplifies the operation even more, with this the process of label template change can be carried out online. The computer network linking scattered labelling workstations enables immediate update of label templates or databases, the update is performed simultaneously for each workstation.

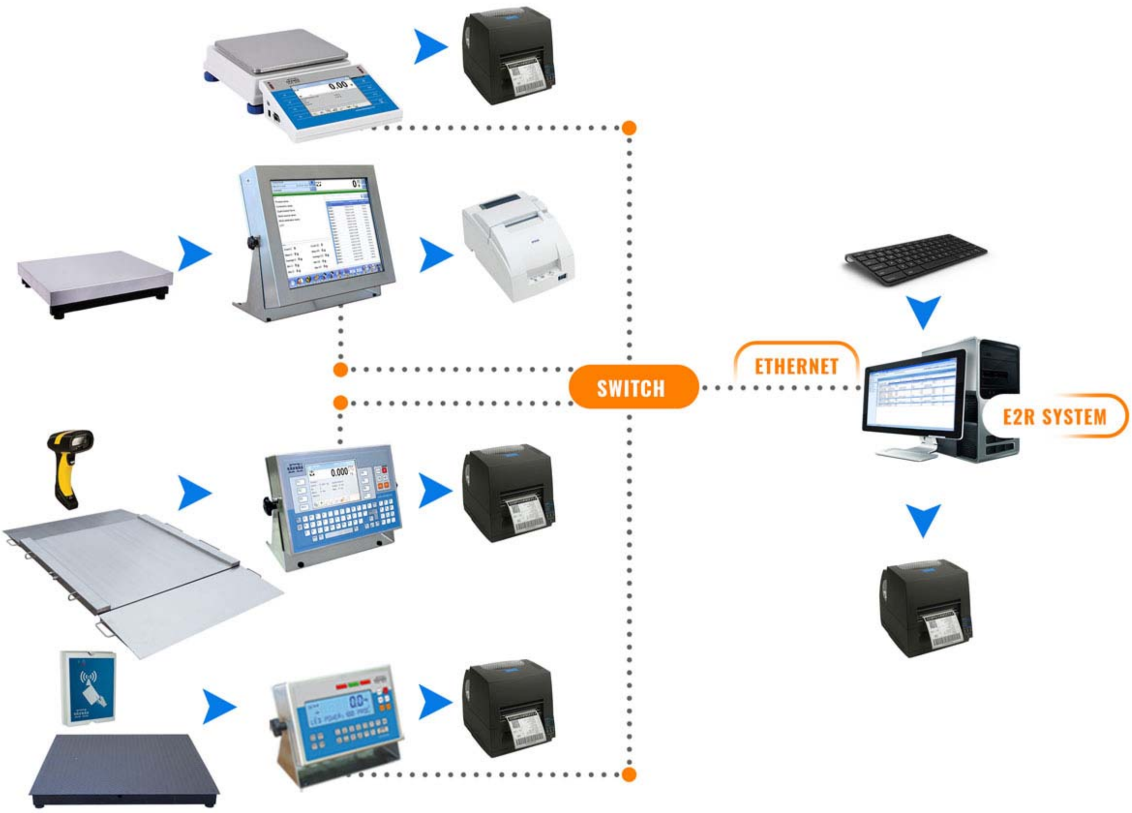


Fig. 64 Exemplary labelling system

Standard functions of the labelling system:

- creating label templates via computer program or with use of the weighing terminal (option dependent on size of the screen). Present tools for creating labels are graphic programs which enable intuitive designing of a new label or editing of the already existing one. Such programs, linked with weighing terminals, feature in-built variables allowing the user to easily determine and locate balance-generated data;
- defining quantity of labels that are to be printed on a terminal-connected printer;
- triggering cumulative label (C label) printout and printout of cumulative label for C labels:
  - manually
  - by label counters status
  - by preset product mas value
- operating as control scale (control of + / - weighing result);
- identifying product by a barcode;
- current update of statistics data upon record of successive measurement into terminal's memory;
- preview of weighings carried out using the terminal, presented in a form of table;
- quick search for product using barcode scanner and RFID readers;
- numerous databases: operators, customers, products, ingredients, packaging types, labels, warehouses, weighings, universal variables;
- weighing reports, possibility to generate simplified report versions with use of implemented modules of simplified reporting;
- managing databases with use of PC computer.

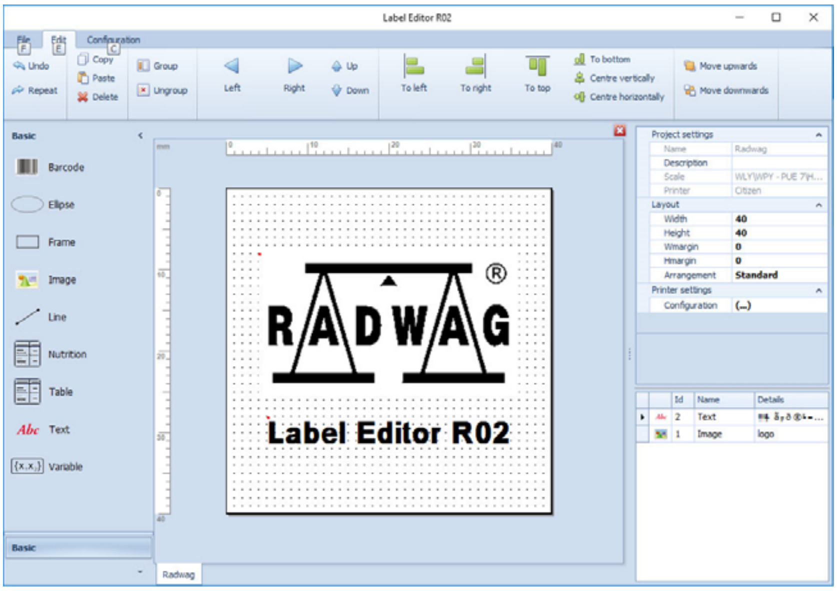


Fig. 65 Label editor PC software

Since the necessity to label products is one of the stages of practically each weighing system: from parts counting, through formulations, filling, to vehicle scales systems, therefore labelling function is enabled for each working mode of the terminal.

The below photo presents weighing system equipped with function of labelling. The operator is to carry out weighing operation on a scale installed on a roller conveyor. The obtained weighing result is sent to a computer system which records it. As a response the computer sends electronic form of a label to the scale, which is next transferred by means of a terminal to a printer. The label is next printed and finally stuck onto a product by an operator.

Fig. 66 Labelling system installed on carcasses partition line

6.3. Filling Systems

Filling systems are most often used functions of industrial scales in processing these days. Similarly to other system solutions the filling systems have developed greatly over the years. From simple function of a weighing instrument they transformed into a standard weighing terminal. Current filling systems offer numerous options and it is up to the customer and his requirements how many of them are used.

A good example of filling system presenting diversity of possibilities is RADWAG designed and manufactured gravimetric filling system intended to dispense edible concentrates into barrels.

Filling system assumptions:

- the system must be fully computerized; computerisation refers to orders issuing, filling and to reporting,
- issuing orders carried out in A city,
- orders realisation carried out in B city,
- possibility of simultaneous filling to 1 - 4 barrels (depending on the order),
- possibility of filling liquid products of various densities,
- possibility of filling liquid products at varying flow rates,
- gravimetric filling of a silo-stored product, where the filling level varies.

The system was designed and realised as follows:

At the workstation where orders are issued, computer software enabling the following options was installed:

- defining databases of users, products, customers, warehouses and operators,
- issuing production orders,
- online transfer of orders to the filling system,
  additionally:
- complex system for analysis of data obtained from the terminals was implemented,
- control over orders in progress, carried out by any computer connected to Ethernet company network was enabled,
- option of defining both preset mass for dosing and dosing thresholds for a given product was introduced.

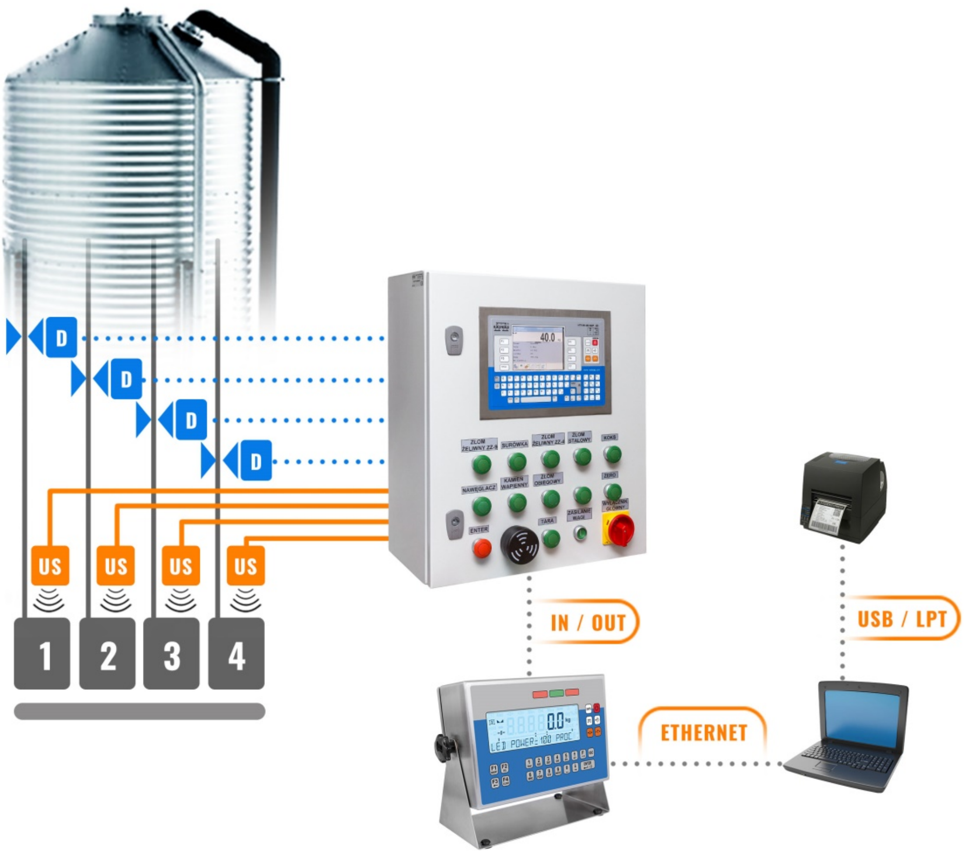


Fig. 67 Filling system diagram

In the plant a system carrying out orders was installed.
The system comprised:

- PUE C41H terminal,
- control valves,
- sensors detecting level of liquid in barrels,
- silo for the concentrate,
- weighing platform of 600/1500 kg capacity with accuracy of 0.2/0.5 kg,
- automatics system with control panel,
- connection with computer system via LAN.

Fig. 68 Filling system

Working Modes

The above presented system required 4 independent working modes to be designed. Terminal's function designed to carry out the filling process applies combined method of determining dosed concentrate quantity, this means that mass measurement is completed with measurement of dosed product flow, which is done in order to eliminate factors related to height of column of liquid in the silo and to liquid viscosity. In the course of order performance the operator decides which working mode is to be used.

- **Sequential filling**

  This working mode is selected manually. Sequential filling consists in filling into selected silos one by one. Filling into a particular silo is a two-stage process. First fast filling occurs wherein the product is dosed until preset threshold is reached, next fine filling takes place. The process ends when mass comprised within preset tolerance range is obtained. Filling set-point for a successive barrel is corrected by a filling error of the previous one. In order to improve sample weight accuracy the terminal carries out filling with reference to speed of liquid flow, with this valves are shut at the right moment thus preventing batch giveaway.

- **Concurrent filling**

  This working mode is selected manually. Concurrent filling consists in filling into selected silos at the same time. First fast filling occurs wherein the product is dosed

until preset threshold is reached, next fine filling takes place. Filling ends when mass comprised within preset tolerance range is obtained.
When it comes to dense concentrate, using concurrent filling mode results with uneven pouring therefore some level sensors may cause shutting of controlled filling valve too early, i.e. when filling is not completed. This means that in some barrels the product may be out of tolerance threshold, however total weight value taken from all four barrels is always correct.

- **Filling droplets**

Filling droplets is a process run automatically by the terminal. In case of low flow rates (flow threshold declared in the parameter), when concentrate droplets dribble down the silo, the dosing algorithm automatically switches to filling droplets mode. For such an instance only part of the algorithm controlling filling works, it is so because this allows to obtain sufficient accuracy. Flow control function gets deactivated and filling is carried out with reference to weight increase data.

- **Manual filling**

Filling system offers operation in manual mode, which is a must in particular cases:

  - the whole cycle controlled manually,
  - operation upon stopping the automatic cycle by pressing STOP + SAVE button,
  - breakdown,
  - maintenance activities.

Use of special dosing algorithms enabled to obtain dose accuracy equal to one scale interval.

Software performance

Database of products that are to be dosed is stored on a PC computer. It is previewed using PUE C41H terminal which also serves to carry out an external order. Operating the terminal the operator can select product, decide whether it is to be dosed sequentially (barrel by barrel) or concurrently, i.e. to all barrels at the same time.
The computer always sends one filling order, i.e. either an order to dose the whole quantity or, in case of sequential filling, one barrel. After completed process the computer reads mass and records data for later processing.

The above provided filling system presents possibilities of terminals operating in cooperation with computer systems. It proves that distance between workstation where orders are issued and place where they are carried out is of no importance, additionally it shows that modern weighing terminal is able to face the problem of variable over time flow rate. These seemingly simple tasks are possible due to complex logical and mathematical algorithms.

6.3.1. Accuracy in Filling Processes

When designing the filling system it is necessary to account for the required accuracy, i.e. the engineer must specify what is the permissible filling error. First condition allowing to obtain satisfactory results, is the right construction of the actuating system. When speaking of liquid filling, the said actuating system is valve of appropriate speed, which shuts-off the liquid at the very moment when the terminal ends the process. The best solution here is so called ball valve with a pneumatic drive. The next as much crucial issue, is option of two-stage control of valves, enabling to feed the raw material with two various rates. This can be done using a frequency converter, controlled via the terminal, which converter, in turn, controls pump feeding the dosed liquid. The first filling stage takes place when the valve is full-opened, in this case the dispensing is carried out with maximum speed. Upon reaching the set threshold the speed decreases in order to allow precise dispensing. An important aspect is distance between the feeding component and a scale. Given the discussed liquid filling system it is the height of valve measured from the weighing platform level. The shorter the distance between the valve and the platform the better. With this the amount of drops of liquid falling down onto the platform upon the valve shut down will be reduced. Compliance with the above specified conditions should provide tangible results. Having designed the actuating system it is time to consider which weighing devices, i.e. platform and terminal, suit the best the requirements. RADWAG-manufactured filling terminals offer complex filling modes, which have been described in the previous chapters of this publication. Their basic assets of great importance when it comes to filling process are:

- fast converter,
- complex signal filtering systems,
- option of manual entering of filling corrections,
- algorithms for automatic calculation of filling correction carried out with reference to previously obtained sample weights,
- numerous digital outputs, enabling control of external actuators.

For industrial scale with resolution of few thousand - several thousand scale intervals and correctly designed filling system it is possible to obtain insignificant errors - even close to zero.

6.3.2. Industrial Metrology in Filling Processes

When choosing industrial filling scale the best solution is to acquire and use a verified instrument guaranteeing process accuracy. In case of devices design of which is based on load cells, there are some limitations imposed by the requirements of legal metrology. In compliance with these requirements resolution lower than 3000 d or, in rare situations 6000 d, is demanded. This imposes serious limitation with regard to potential accuracies that are possible to be obtained in the filling process. When the scale is just a technological equipment which serves purposes other than billing of commercial transactions and its verification is not required, then the resolution can be increased and thus filling errors reduced. Modern terminals and platforms offer several times higher resolution. RADWAG has implemented numerous solutions using weighing instruments with resolution of 15 000d, and in exceptional cases of 30 000d. However, it should be remembered that if the actuating system is defective then scale of such high resolution cannot guarantee correct process.

6.4. Formulation Systems

Formulation system can be called a multi-ingredient filling system. Development of formulation systems is an answer to demands of present-day industry calling for ingredients mixing. Operation of ingredients mixing is present in every single area of industrial production, starting from concrete plants, through food industry, to chemical industry, however characteristics of such operation vary among the industries thus customized approach to formulation procedure is required.

Due to this diversity the modern formulation systems operating on the basis of weighing terminals feature complex formulation modules offering the customer a lot of flexibility when it comes to selection of respective formulation method.

Fig. 69 Formulation system diagram

Formulation processes can fall into one of the following categories:

- manual formulation,
- automatic or semi-automatic formulation,
- combined formulation.

The first category comprises weighing systems where the formulation process is performed manually, i.e. such systems where the weighing pan is loaded with the product by hand.

The second category comprises industrial systems, where formulation is carried out automatically by means of automatics controlled by the weighing terminal.
This category can be subdivided into fully automatic weighing systems, designed to enable performance of the complete formulation without interference of an operator, and semi-automatic systems, which require the operator to confirm completion of dosing of each ingredient one by one.
The third category comprises systems combining features of both 1st and 2nd category instruments, such ones which demand part of the ingredients to be dosed automatically and part manually, e.g. improvers and additives which are added by hand.

The formulation process begins with creation of the recipe and entering it into the terminal. This is where the first problem occurs. If the recipe has been created to produce dough for 10 loafs of bread then what should be done to provide dough for 20 loafs? Of course one of the possible solutions is to carry out the recipe twice but what if 25 of 73 loafs are to be baked? In case of such requirement modern weighing terminals recalculate weight values for every single ingredient of the recipe. Recalculation involves entering of the recipe multiplier with reference to which the whole recipe gets modified. The terminals enable the order to be carried out on few platforms of different capacities and readabilities, this is especially useful when weights of particular ingredients differ significantly.
In the course of manual operation it may happen that one of the recipe ingredients is dosed in excess, this of course influences the mixture negatively. For such an instance it would seem reasonable to abort the process, utilize all the ingredients and start the whole cycle from the very beginning. Fortunately the terminal monitors whether the recipe is carried out correctly therefore when excess of one of the ingredients is detected then mass of the remaining ingredients gets automatically adjusted. First come the ingredients following after the excess one, next those that have already been dosed prior detection of the excess ingredient. With this, recipe proportions are maintained. The condition for successful completion of the recipe is not to get out of the max capacity range, neither mass of a single ingredient (depending on formulation mode) nor the whole recipe shall exceed the permissible max threshold value.
As for method of terminal or user's operation coming after a single ingredient has been dosed, there are two options. Either successive ingredients are added one by one making a mixture and the scale is tared each time a new ingredient has been added or the dosed ingredient is removed by an operator in order to provide space for the next one and the scale gets zeroed automatically.
In case of the second option the scale can be used to weigh an ingredient of mass several times greater than the max capacity value, this is possible due to weighing in so called batches. Weighing in batches requires specifying what part of total weight or what percent of total weight is to be measured. This is determined in the course of creating the recipe.
Formulation systems offer monitoring of the operator, his (her) work is controlled via the weighing terminal. It is natural that people make mistakes, it may happen that the operator instead of weighing ingredient A doses some other ingredient, B for example. Luckily the terminal can verify it, for verification purposes the ingredients are checked using external barcode scanners. With verifying option turned on, the terminal first controls whether the

right ingredient has been selected (barcode is read), when everything is correct the dosing process starts.

The above provided information leads to a logical conclusion that modern formulation systems are high-tech solutions meeting the most demanding requirements of potential customers.
If the formulation system is combined with a computer then its functionality gets considerably boosted by allowing performance of database-related operations. With this it is possible to integrate the formulation systems and warehouse management, which means automatic monitoring of inventory, inter-warehouse transfer, automatic removal of products form the stock in accordance with an ongoing recipe and registering of ready-made mixtures on the stock.

6.5. Systems for Control of Pre-packaged Goods

Valid legal regulations regarding pre-packaged goods control are *Law of 7th May 2009 on pre-packaged goods* and *Law of 22nd October 2010 amending the law on pre-packaged goods*. The laws specify regulations on both packing into single packs those goods which are to be put onto the market and marking the products with „e” mark. The said laws also determine how to manufacture measuring container bottles.

The law lays down numerous requirements that have to be fulfilled by pre-packaged goods manufacturers marking the products with ℮ mark.
The most fundamental ones are:

- the manufacturer is obliged to provide plan of adopted internal system controlling pre-packaged product quantity, the plan must be submitted to the Director of regional Office of Measures no later than 60 days prior start-up of the packing process (Art. 16),
- the manufacturer is obliged to document in writing every single internal control aiming to monitor pre-packed product quantity, the documentation must be presented in a form allowing the administration body to examine time and place of control, batch quantity and sample size, as well as control results; additionally it must state whether the observed error stays within permissible limits and whether particular batch meets criteria for approval when it comes to putting the controlled product onto the market. (Art. 18, section 1),
- on request of the administration body the manufacturer is obliged to make respective control-related documentation available for analysis (Art. 18, section 4).

The above requirements make every manufacturer marking his products with ℮ mark implement an internal control system monitoring the pre-packaged goods. Such system, apart from procedures describing principles of operation, must consist of instruments intended for PGC control. Manufacturers of other than e marked products are also obliged to perform the control, the only difference is that they do not have to archive the results.

Nowadays many producers, RADWAG among them, offer complex PGC-related services. First they help their customers to select the most appropriate device (characterised with the right readability), next they organise the system installation and finally run it.
Modern PGC systems may be divided into two categories:

- independent, single control workstations,
- integrated network-operating systems.

Single workstation system comprises scale equipped with respective software and printer enabling reports printout.
Network system comprises at least one scale connected with a computer system via LAN, which computer system manages the control process.
With use of weighing terminals characteristic of user-friendly interface and featuring an in-built database system the difference between the two categories seems to be quite insignificant. Up-to-date network systems are designed in a way enabling any system-operating scale to start, perform and complete control in case of the master computer or network breakdown. This is possible due to the fact that each weighing device stores complete database of products and operators. All the performed controls are recorded by a scale and sent to a database server immediately after successful reconnection.
The customer can simply purchase single workstation system and next expand it to a network system.

Fig. 70 Network PGC system diagram

In accordance with law regulations the weighing systems offer two methods of control of pre-packaged goods:

- 100-percent control - kind of control carried out mostly with automatic scales,
- statistical control – kind of control where random batch samples are selected and checked.

100-percent control consists in weighing of all products form a particular batch in order to check their masses, which is done taking into account law specified criteria (more detailed information on 100-percent control is to be found in chapter describing checkweighers).

There are two types of control carried out by non-automatic systems:

- control performed using reference method – legislator recommended control,
- control performed using internal method – modified reference method, where the user himself specifies control criteria changing the following parameters:
  - batch quantity,
  - control duration,
  - values of negative T errors,
  - values of positive T errors,
  - coefficient used for calculation of permissible average limit,
  - control end method; including the following cases:
    - when required quantity is obtained,
    - when permissible control duration comes to an end,
    - when permissible control duration comes to an end or when required quantity is obtained,
    - when permissible control duration comes to an end and when required quantity is obtained.

6.6. Systems of Static Measurement on Vehicle Scales

In many factories the process of goods registering begins at the very moment when the truck enters the plant gates, right before unloading. The goods are registered using vehicle scales. Weighing at the plant gates takes place twice: first when the loaded truck enters the plant, next when the unloaded truck leaves the site. This allows to easily calculate mass of the load itself, neglecting weight of the truck. Measurements on plant entrance and on exit are often basis for potential complaints or settlements of transactions therefore it is very important to carry them out with verified instruments. It is obvious that measurements performed using device that lacks valid certificate have no legal force and can be questioned.

Fig. 71 WMT vehicle scale

A good example of the above described weighing solution is RADWAG-manufactured load cell scale of WTC series presented in the photo above. Depending on the customer's requirements it is manufactured either as an uplifted version (see the photo), i.e. such one where the platform and the ground are at two different levels, or as a pit version, i.e. such one where the platform and the ground are at the same level. EC Type Approval Certificate, max capacity of 60 000 kg and scale interval e=20 kg along with 18-meter long and 3-meter wide weighing platform allow weighing of almost every single truck. Standard vehicle scale set comprises: concrete-made construction, six load-cells, weighing module and a terminal.
The weighing operation itself is uncomplicated and it does not differ from those weighings that are carried out using any personal, medical or industrial scale. However when it comes to interpretation of the obtained results the case seems to be much more difficult. In order to get net weight of the vehicle-stored load two measurements are required and unfortunately the difference between the measured and declared load mass can be observed no sooner than in the course of the second weighing. That is the moment when the operator starts wondering whether the first measurement had been carried out correctly, whether there were no people standing on the weighing platform, whether the driver was sitting in the cab, whether some other measurements have not been referred to by mistake and finally whether weighing number one and weighing number two are weighings carried out for one and the same truck.
In order to eliminate mistakes of human origin automated weighing systems are frequently used as a solution which ensures clarity.

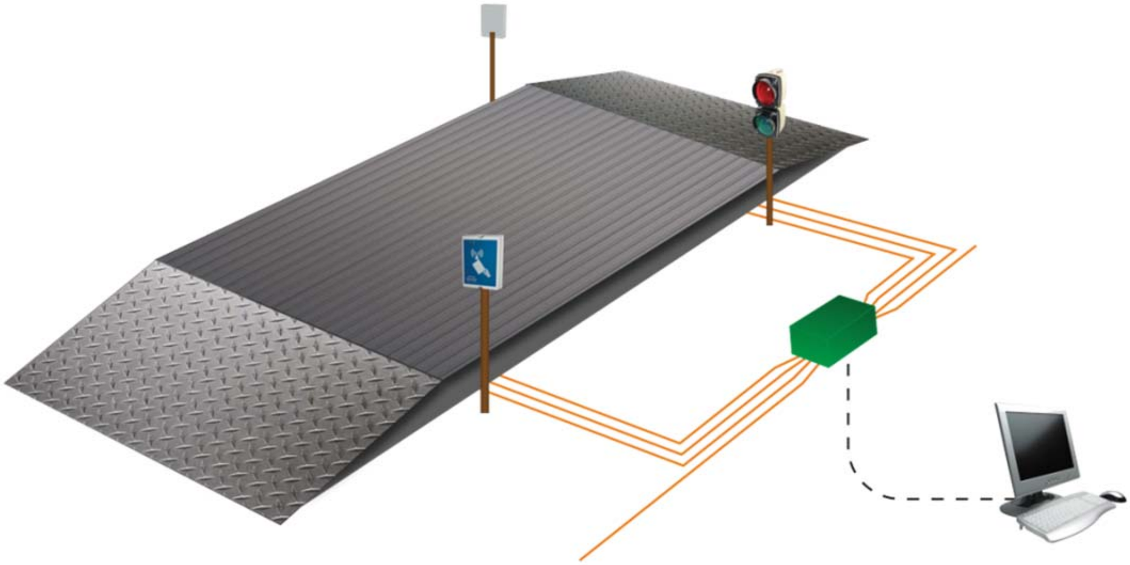


Fig. 72 System of vehicle scales mass measurement

Vehicle scales are connected to computer systems that aid an operator performing the measurement and ensure archiving of the whole measuring process.

The most standard system installed along with the vehicle scales is a system of cameras, wherein the cameras are arranged in a way allowing to monitor each side of the truck and to view the licence plate with car's registration number. The cameras help the operator to quickly assess whether the truck takes the right position on the platform, and make sure that no other objects are resting on it. He can also check how many people are sitting in the cab. As it has already been mentioned the system of cameras facilitates readout of the registration number. At the very moment of performance of the measurement the photos taken by cameras can be captured and recorded in the computer system database for potential verification purposes. This solution helps to clearly identify particular weighing which in case of any doubts can be analysed. The system of cameras improves the weighing system making it more advanced nevertheless it does not prevent occurrence of latent human errors, i.e. incorrect assigning of weighings of an empty and loaded truck. Therefore another identification system has been designed to operate simultaneously with the cameras. The second system is responsible for automatic detection of truck, possible using transponder card which card is owned by a truck driver. Upon entering the scale the driver logs on to the computer system via transponder card reader or with use of RFID system, which thanks to a chip installed in the truck automatically detects the vehicle.

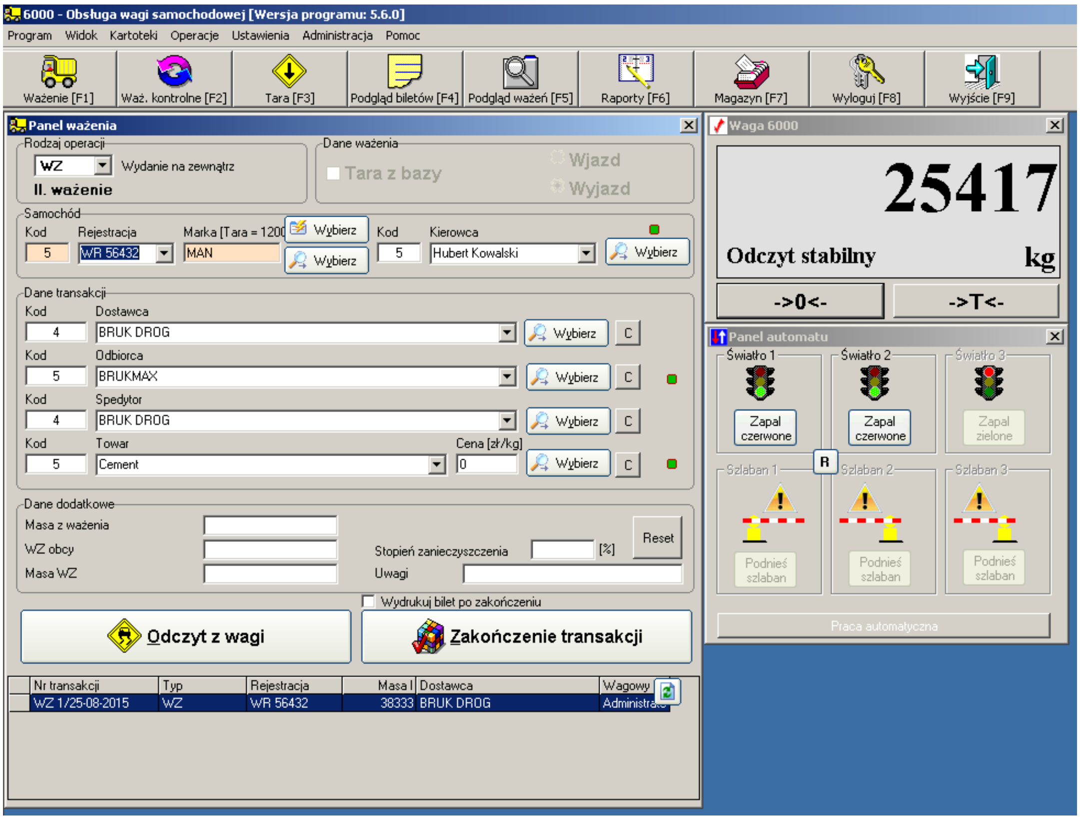


Fig. 73 Exemplary screen of vehicle scale program

Vehicle scale equipped with both of the above described identification systems reduces operator's role to control of traffic lights and barriers that inform the truck driver when to enter and exit the scale (however operation of these two can also get automated).

Measurements carried out on vehicle scales are a substantial issue when speaking of transfer of goods from one plant workstation to another. Missing measurement of one vehicle only, means several dozen tons of unrecorded products, therefore many consignees decide to purchase and install in their plants fully automated systems comprised of vehicle scales allowing measurement of trucks.

7. Weighing Systems Operating on the Basis of Automatic Scales, Intended for Single Loads

Fig. 74 Checkweigher intended for single loads

With rapid development of weighing equipment and weighing systems the difference between automatic and non-automatic solutions has become much less apparent these days. It often happens that classifying a given system unequivocally and fitting it into a particular category is a challenging and difficult task. Such situation is a frequent case when non-automatic weighing instruments are part of complex systems of automatics.

Definition of an automatic weighing instrument provided by MID directive, stating that it is simply an instrument determining the mass of a product without the intervention of an operator and following a predetermined programme of automatic processes characteristic of the instrument, is not clear enough. Used terms 'operator' and 'automatic process' are not as precise as necessary. Theoretically each weighing equipment operates in accordance with an algorithm concerning the weighing cycle, and the operator (human) is often replaced with external control systems. The question arises whether in such case we speak of automatic process or not? As for today there is no unequivocal answer to this query - it is the body granting certificates and the officials performing instruments verification who according to their interpretation decide on the above. Ongoing works regarding MID directive revision will hopefully supply the readers and anybody whom it may concern with unambiguous, precise definition of an automatic instrument.

The problem of classification ceases to exist when speaking of checkweighers with type approval since they are independent machines equipped with their own automation systems.

Checkweighers for single loads are divided into categories with regard to instruments design and load transfer method:

- The first group comprises non-automatic weighing instruments modified in order to be used for automatic weighing processes. Most frequently, these are standard instruments equipped with weighing pans onto which the loads are transferred using actuators and from which they are taken upon completed measurements using actuators too. Non-automatic scales of this type do not have Type Approval certificate for automatic weighing instruments.
- The second group comprises non-automatic scales that, similarly to instruments of the first group, are equipped by the users with conveyors transferring the products.

These scales also do not have Type Approval Certificate for automatic weighing instruments.

An example of such solution, or actually a combination of both above described solutions, is a non-automatic weighing device presented in the photo below, equipped with roller conveyor and hydraulic lift system. It operates as follows: the product goes down the conveyor, as soon as is gets detected within the weighing station area the weighing unit located underneath the rollers is lifted up with use of the scissor lift, as a result the product primarily resting on the conveyor now rests on the weighing unit components (protruding above the rollers line) that transfer the measured object weight onto the weighing mechanism, the measurement starts. Upon completion, the weighing unit drops down making the product rest on the conveyor again, now the product leaves the weighing station.

Fig. 75 Non-automatic scale integrated with a conveyor system

- The third group comprises typical automatic weighing instruments intended for single loads. These machines are equipped with weighing conveyors by standard and have been designed and manufactured in a way ensuring fully automated weighing process. Automatic scales produced by RADWAG feature Type Approval Certificate and can be verified.

Fig. 76 DWT/RC series checkweigher

- Rotational automatic weighing instruments have been designed with the intention to enable weighing of cylindrical products with high centre of gravity, e.g. bottles, deodorants, sprays. Transfer of products of this type from one conveyor to another is a quite complicated issue, the high centre of gravity often makes the cylindrical products fall down when leaving a line conveyor and entering a weighing conveyor. This is the reason why the rotational automatic scales do not feature their own conveyor belts, the product is taken directly from the production line conveyor and after being weighed fed right back onto it. Automatic scales produced by RADWAG feature Type Approval Certificate and can be verified.

Fig. 77 Rotational automatic scale

- The forth group comprises automatic overhead rail scales. These have been designed to be installed into rails system of meat and poultry processing plants. They are intended to enable automatic weighing of half carcasses hanging down the transport hooks. Means of operation for overhead rail scales and for belt conveyor solutions is identical. Half carcass hanging down the hook is weighed automatically while being transported. Automatic scales produced by RADWAG feature Type Approval Certificate and can be verified.

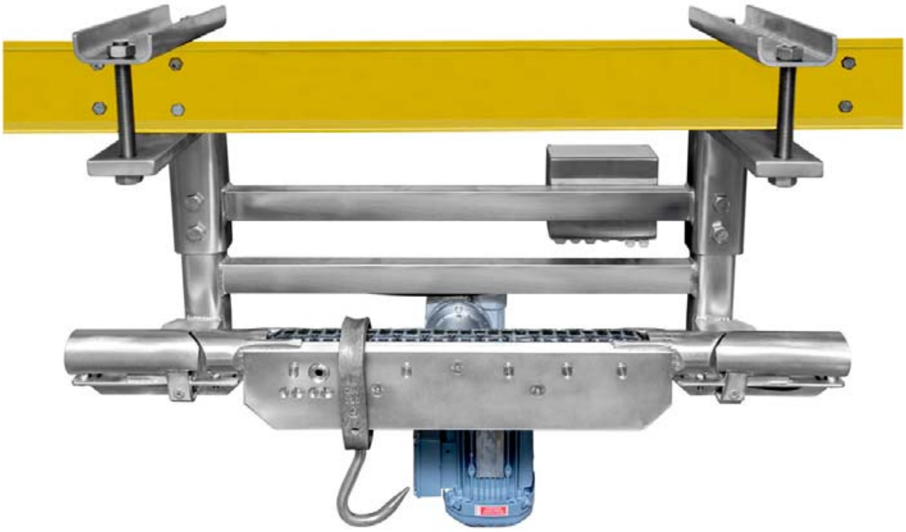


Fig. 78 Automatic overhead rail scale

7.1. Strain Gauge Weighing Cell Technology in Automatic Scales

Basic and the most commonly applied measuring systems when speaking of industrial solutions both automatic and non-automatic, are **strain gauge transducers,** i.e. load cells intended to measure force (mass).

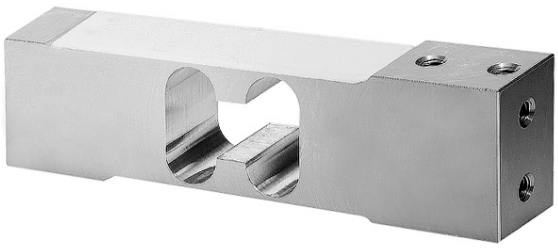


Fig. 79 Load cell

The load cells have been characterised in details in chapter 3 which supplies also information regarding means of their operation.
Strain gauge weighing cell technology is popular wherever automatic measurement is performed, it is mostly due to the fact that the load cells and weighing modules equipped with strain gauge transducers are commonly accessible. Another reason facilitating frequent use of this solution is designing automatic scales on the basis of non-automatic weighing

instruments - through installing a conveyor or some other automatic load transferring system and integrating it with the already existing construction.

Other devices as commonly applied as strain gauge transducers are **electromagnetic converters**, also widely discussed in chapter three.

In weighing instruments operation of which is based on this converter, the exerted force does not cause deflection of straight-line mechanism. Such solutions work on the basis of equilibrium, with this high resolution is possible and the indication errors remain small. Electromagnetic converter design facilitates compensation of weighing pan mass which in case of precise automatic scales intended for measurement of single loads is of great importance. Weighing pan of instruments determining mass of single loads is a weight carrier mass of which falls within a range of few kilograms, this value is few times greater than mass of a weighed product.

Fig. 80 ***Electromagnetic module of MWMH series***

7.2. Automatic Weighing Systems - Means of Operation

Prior learning about methods of weighing with use of automatic instruments, it is worth to find out what is the principle of operation of non-automatic scales since this principle is fundamental for most automatic solutions.

The graphs below present process of weight increase from the moment of depositing the load on the weighing pan to the moment of obtaining the result. The first graph shows curve for scale with wide stability range set, the second demonstrates curve reflecting narrow stability range. For both graphs the same digital filter for curve of weight increase was adapted.

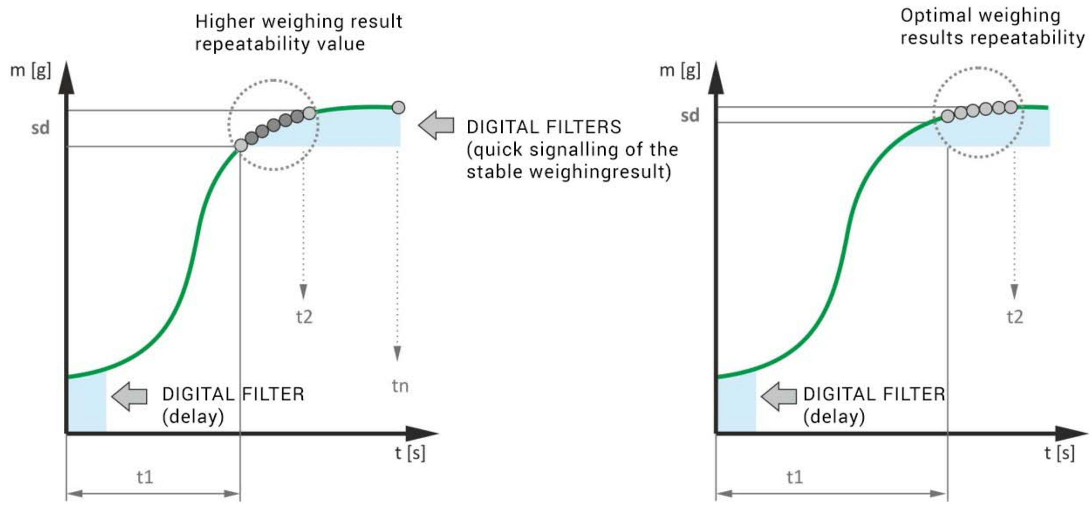


Fig. 81 Measurement performed using static scales

where: t1 – time interval of weight signal increase
t2 – measurement end, stable result
sd – range of stable result check

In both cases time t2-t1 is the same; however on graph no. 1 the sd function is activated earlier thus allowing to obtain stable result faster, unfortunately this may result with greater measurement error. On graph no. 2 the measurement result is more reliable but it takes more time to obtain it. When speaking of automatic scales, where weighing rate is of great importance, setting sd range is kind of a compromise between speed and accuracy. Another critical issue here is to adjust filtering signal respectively in a way ensuring prompt reaction to loaded mass.
Automatic weighing instruments classified in subchapter 2.5 with regard to weighing method and way of obtaining the final result may be divided into three groups:

- Gravimetric filling instruments, discontinuous totalising instruments, rail-weighbridges.
  Weighing result is obtained similarly like on non-automatic instruments, by providing stable indication being either a final outcome of the measurement or, in case of combined solutions, a part of final total mass.
- Conveyor belt instruments.
  In case of these solutions temporary measurement is obtained, the measurement is recalculated using mathematical formula which additionally takes into account area of weighed surface and conveyor speed, next the measurement is added to the total value.
- Weighing instruments for single loads.
  Means of operation in this case differ from those of remaining instruments types, it is due to both high speed and capacity.

Standard automatic weighing instrument intended for single loads offers throughput many times greater than throughput of the fastest static scale. For static scale the throughput ranges between 15 – 25 pcs/min. This in case of a dynamic scale is an extremely low value. Weighing instruments for single loads are characteristic of throughput equal 100, 200 and even 600 pcs/min. This huge difference is a reason why dynamic scales' systems operate in a completely different way.

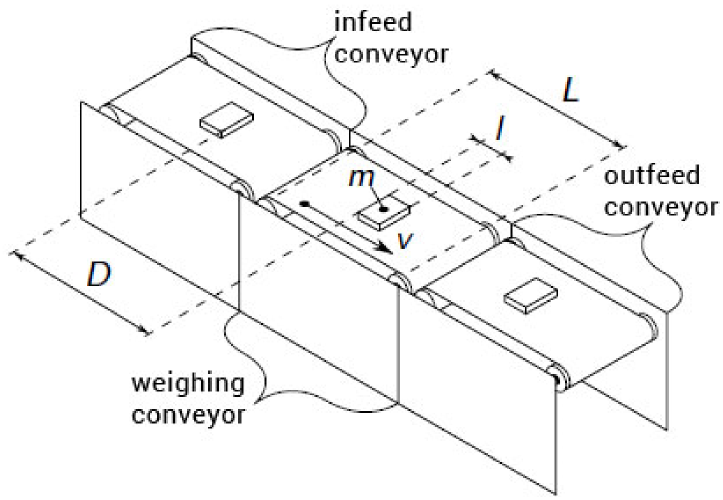


Fig. 82 ***Weighing performed using dynamic scale***

Standard weighing instrument for single loads comprises three conveyors:

- an infeed conveyor, moving with speed equal to speed of a weighing conveyor, which is necessary to avoid errors being a result of potential product sliding, and to enable stabilisation and smooth transfer of the product onto the weighing conveyor;

- a weighing conveyor, the one where weighing process takes place, which weighing process is performed within t time, where:

$$t = \frac{L - l}{\vartheta}$$

  where:

  t – time interval within which the product rests on the weighing conveyor
  L – weighing conveyor length
  l – product length
  v – conveyor speed

  Analysing the above formula leads to a logical conclusion that measurement duration depends on conveyor speed and difference between length of weighing conveyor and product. Each manufacturer offers unique minimum weighing time allowing to obtain the result.

- an outfeed conveyor overtaking the weighed product form the weighing instrument.

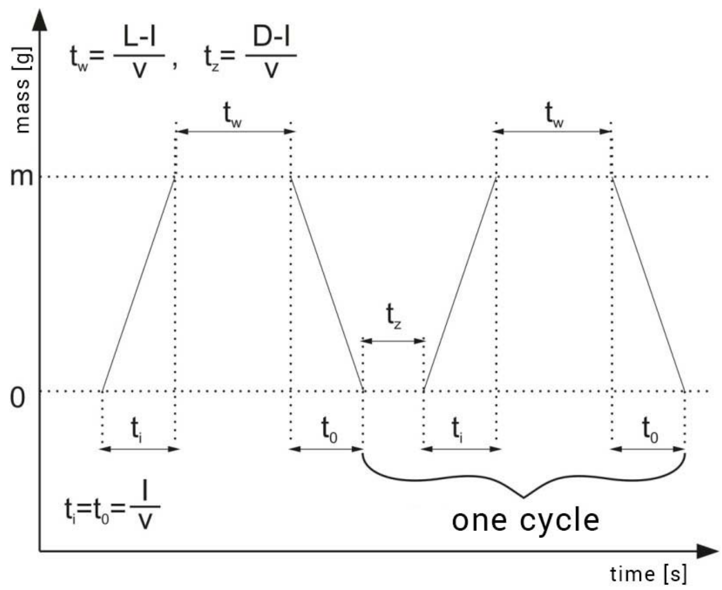


Fig. 83 ***Graph of mass, visualizing product passing down the weighing conveyor***

where:

t_w – weighing time interval
t_z – time interval within which the conveyor remains empty
t_i – time interval within which the product enters the weighing conveyor
t_o – time interval within which the product leaves the weighing conveyor
v – speed
L – weighing conveyor length;
l – product length;
D – space between successive products

The above graph shows two cycles of product passing down the weighing conveyor. At start the weighing instrument remains unloaded, when empty it controls and corrects zero indication. At the moment when the product enters the weighing conveyor, the weight value increases. Now, with the product going down the weighing conveyor, weigh value is calculated. Next the product leaves the weighing conveyor, the cycle comes to an end.
Analysis of the above graph leads to the following conclusions:

- the weighing conveyor must be longer than the weighed product, most frequently recommended length difference is about 15-20 cm,
- while the product passes down the conveyor it is forbidden to touch it, stop it etc.,
- the product must pass all the way down the weighing conveyor (from the start to the end), it cannot be dropped onto it or removed from it half-way before the end of the cycle,
- in the course of weighing it is forbidden to change conveyor speed,
- in the course of weighing it is forbidden to touch either the conveyor or the product.

Since real curve of mass is distracted by external factors, mainly by the weighing conveyor, then obtaining such curve that would allow calculation of the weighing result is a difficult task. The graph below presents real, continuous readout of mass of load passing down the weighing conveyor.

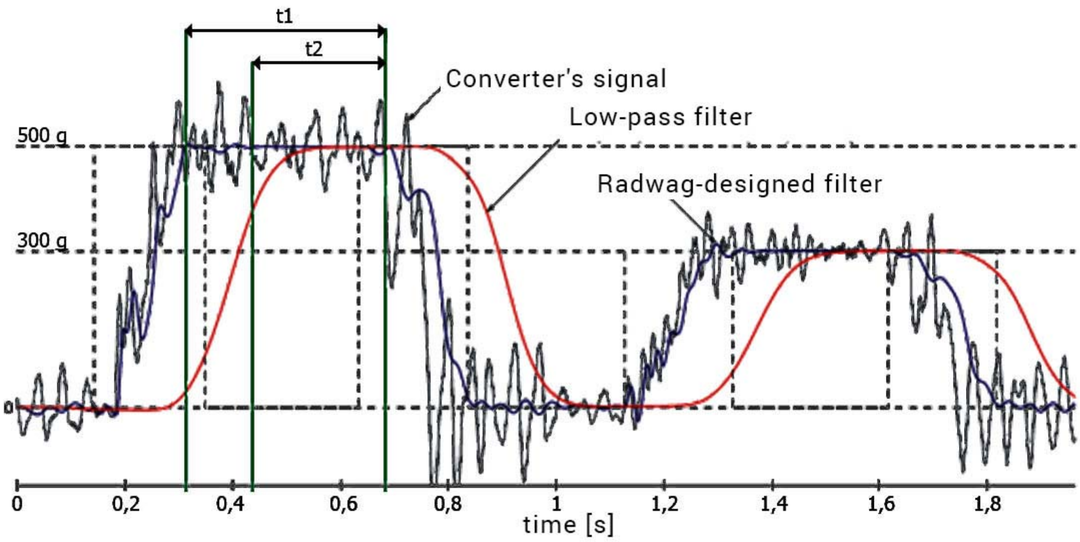


Fig. 84 ***Real curve of mass for dynamic scale***

where:

t1 – time interval within which the product passes down the weighing conveyor

t2 – part of curve of mass on the basis of which weight value is calculated

Signal from a converter (real curve of mass) must be filtered first, which with use of standard filtering modules causes serious delays and curve rounding. Use of not strong enough filters does not help to remove noises, whereas too strong filters make the curve take form of sinusoid with which calculation of weight value is impossible. This is a reason why manufacturers of dynamic weighing instruments often apply self-designed filtering algorithms, such ones that immediately react to increase of weight when the product enters the weighing conveyor, and which next in the course of product passing down the conveyor respectively filter noises in order to provide smooth, long curve of mass. Only smooth, long curve of mass makes calculation of weight value possible. Out of the time interval **t1** the most stable curve fragment **t2** is selected, next this fragment serves as a basis for calculation of final weight value which is done by means of averaging or some other mathematical algorithm.

7.3. Pre-packaged Goods Control

Law of 6th September 2001 on pre-packaged goods as amended, orders control of all pre-packaged goods which are to be put onto the market. In consequence all the manufacturers are obliged to control weight of their products.

Most production lines have been equipped with non-automatic weighing systems cooperating with computer software enabling law-accordant control with use of reference method (control of batch based on randomly selected sample).

This solution guarantees compliance with legislator-specified regulations regarding weight but it does not meet requirements of the manufacturers that aim to cut production costs.

Control system based on reference method causes production cost increase which, apart from contributing factors such as purchase price and system service costs, is generated by frequent reweighing of manufactured products samples. What is more, such system does not ensure successful, completely reliable control of manufactured batch. If a tested sample fails to pass the control then the whole batch must be utilised or packed from scratch which is a costly operation.

Even though the investor owns an expensive control system operation of which is based on reference method, he cannot use it for the purpose of optimisation of packing machine settings.

This is why systems for control of pre-packaged goods comprising non-automatic weighing instruments are either replaced with automatic solutions or equipped with automatic weighing instruments allowing 100-percent control.

According to law, 100-percent control consists in checking average weight value for a whole batch, which value cannot be lower than the nominal value. Applying this criterion as one and only is not effective due to the fact that in case of large batches, the average value is greater than nominal one and either an underweight product, or even an empty pack, do not result with lowering of the average value. This does not bring about rejection of the faulty product. In order to avoid the above, most manufacturers of automatic weighing instruments have introduced additional control criteria aiming to monitor correctness of particular batch; the first criterion is so called 2T1 value - any products with weight lower than 2T1 value are rejected, the second is quantity of T1 errors - if the error occurs more times than permissible then the product gets conditionally rejected, rejection here depends on batch quantity and on quantity of faulty products with weight lower than T1 error value.

Currently the weighing market offers two leading software solutions designed for automatic weighing instruments, which aim to enable control of pre-packaged products.

The first solution uses instrument equipped with rejecter which discriminates products in accordance with operator's settings, eventually products of weight lower than Qn – 2T1, and keeps statistics on remaining products, those that have met the criteria and are stored in a warehouse. One fundamental drawback here is the fact that even though part of evidently faulty products gets rejected, it is never known whether the control will end with success. Still it may happen that the average value will be lower than the nominal one.

Another, much more advanced logic solution applied in automatic weighing instruments is online monitoring of all control criteria. In this case weighing software contains all limit values concerning control. The software operates as follows: at start of new batch production the weighing instrument takes as a basic criterion the fact that the ongoing batch must comply with law requirements at any moment of operation. To enable this, the logical algorithm must follow the below procedure:

- the weighing instrument specifies values of T1 and T2 errors for a given product;
- upon completed weighing the following conditions are checked:
  - whether the obtained value does not exceed 2T1 error,
  - whether the obtained value does not exceed T1 error, if it does then the software checks whether such error may occur for this particular batch quantity (according to the law 2% of products with weight range 2T1 - T1 are permitted),

- whether average value does not become lower than the nominal value in case of finding the product compliant with the criteria.

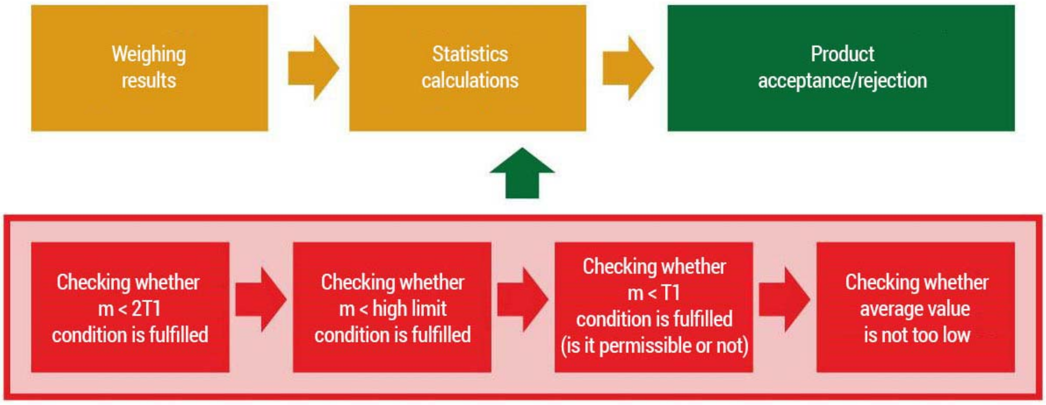


Fig. 85 PGC control algorithm for Radwag-manufactured automatic weighing instrument

Constant works concerning optimisation and reduction of production cost, make many manufacturers implement controls of pre-packaged goods in accordance with internal criteria. By lowering permissible errors' values, the manufacturers are able to minimize loss and improve repeatability.

RADWAG-manufactured weighing instruments enable setting user-specified T1 error limits, ranging from 0 to legislator-specified value, instead of using permissible errors exceeding T1 value.

Valuable asset of automatic weighing instruments designed to perform pre-packaged goods control are computer systems enabling record and processing of particular weighings.

Combination of scales controlling 100 percent of manufactured products and a system recording and processing weighings offers plenty of opportunities when it comes to control of manufactured product quality.

7.4. Procedures of Control and Verification of Operation of Automatic Weighing Instrument

Basic control procedure is the one specified by the Central Office of Measures. Its description is to be found in publication titled *Guidelines for Beginners*.

According to the procedure the automatic weighing instrument should be tested once a week. For the purpose of weekly tests, 30 packed products need to be weighed and the results of particular weighings recorded. Next weight of these 30 packed products must be determined using non-automatic weighing instrument with verification interval adjusted respectively to the real quantity but not exceeding 1/5 of automatic weighing instrument's verification interval. Next it is necessary to determine difference between weight values indicated by these two instruments.

The automatic weighing instrument is considered to be defective if:

- the difference of weighing results in at least one case is greater than 0.2 $T1$,
- average value of weighing results differences exceeds 1/2

of the verification interval.

The procedure although very precise is quite complicated and labour-consuming. Due to this, simplified procedures are often applied in practice, they require one sample to be weighed numerous number of times using the automatic weighing instrument. If the tested product is representative for the whole batch (it is in no way different form other products both in terms of size and weight) then such test is comparable with the one recommended by the office.

Wherever constant presence of the operator in the course of the manufacturing process is required in order to watch the packing machine, usually placed in a vicinity of the control scale, the control is carried out continuously. In specified time intervals the operator takes sample weighed on an automatic weighing instrument and weighs it using a non-automatic weighing instrument, then compares the obtained results.

All in all, it is the product manufacturer who decides on control method and how often his weighing instrument is tested.

7.5. Metal Detectors

Development of automatic systems for control of pre-packaged products weight and necessity to inspect food in order to eliminate potential contamination have resulted with integration of two control workstations into one.

Fig. 86 ***Weighing instrument with metal detector***

An integrated workstation is a useful solution in every aspect. The dynamic scale must feature conveyor feeding the product whereas the detector must be equipped with a special

transporter not disturbing its operation. Combining these two into one saves space and reduces costs.
Typical automatic weighing instrument is equipped with system rejecting overweighed or underweight products therefore adding another system of discrimination, which would eliminate products that are contaminated, is not a problematic issue. Integration of detector and scale into one device facilitates consolidated reporting and operation of two different units via one terminal.
Quite important distinction between the weighing instruments and detectors is the fact that the former ones can be issued metrological certificates whereas the later are not subjected to any standards providing requirements for sensitivity or detection accuracy. This is an effect of many factors influencing detection rate, e.g.:

- type of package, magnetic and electrical properties,
- product temperature,
- product density,
- water content,
- detecting gate size.

Due to lack of respective standards, the requirements for detector's sensitivity are specified by product consumers; often auditors inspecting the plant.

7.6. Automatic Weighing Instruments With Labelling Function

Automatic weighing and labelling systems, just like systems for control of pre-packaged goods, have been designed to improve performance of workstations equipped with non-automatic machines. They are a combination of automatic weighing instrument for single loads, labelling device and labels applicator. Depending on process requirements the labelling system may apply labels onto the package from any side: top, bottom, front or left – as presented in the photo. Option of concurrent labelling of one product with many labels is available, this kind of labelling is characteristic for products supplied to large stores. Such products require application of brand label in front and informative label at the back.

Fig. 87 Weighing instrument intended for labelling of boxes

The below photo presents multifunctional labelling and controlling system enabling:
- control of weight,
- rejection of overweight/underweight product,
- labelling the product with scale-generated label from top,
- labelling the product with scale-generated label from bottom,

➢ printout of cumulative label, generated with use of additional hand labelling device (not to be found in the photo).

Fig. 88 Top - bottom labelling system.

RADWAG labelling systems of DWM xxx E series enable concurrent operation of three labelling devices and simultaneous application of three different labels. These systems can be a part of combined weighing solution comprising both automatic and non-automatic weighing instruments.

For non-automatic scales and for DWM xxx E series systems, the label template is designed using computer software **Label Editor**. This favours use of one and the same label design on all RADWAG weighing instruments. Using either computer or scale the operator can assign particular label template to a given product and determine by means of which labeller it is to be applied. Upon selecting a particular product out of the product database the system automatically determines which labellers are to be used and what data is to be sent. Next the weighing operation is performed, when completed the labels are automatically sent to the printers. After weighing a declared quantity of pieces or after obtaining a preset weight value, cumulative label is printed.

Particular label template can be modified using a computer system, computer-modified label template is automatically updated on a scale.

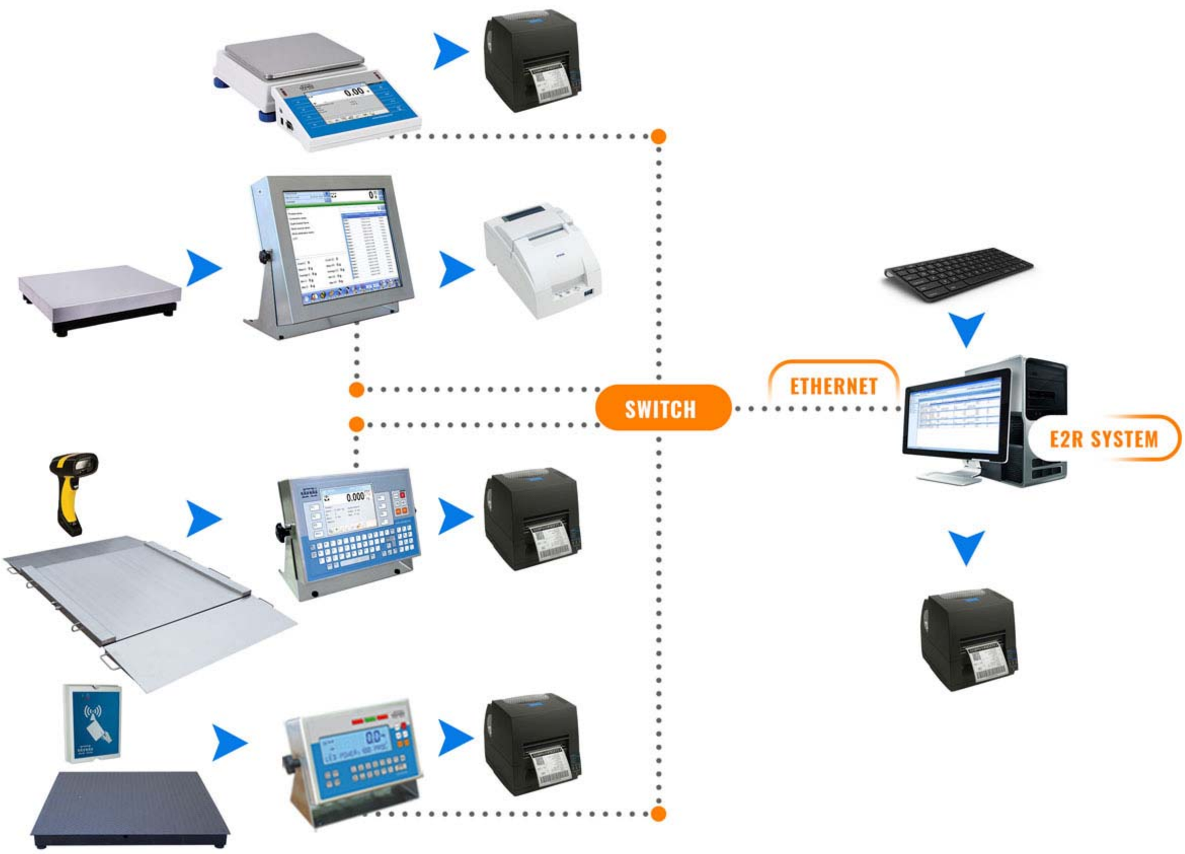


Fig. 89 Combined labelling system

Labelling systems are used mainly in industry plants manufacturing food products of variable weight, i.e. pre-packaged goods mass of which changes, for example meat, cured meat, poultry, fish.

Registration of weight of bulk packed products, transported in containers or boxes also requires use of labelling systems. One of good examples would be meat delivered to stores in transport boxes, which boxes feature labels providing data such as box mass, expiry date and other.

Performance of automatic weighing instruments designed to enable labelling depends on assumptions taken into consideration at the moment of putting an order. It is going to be high if respective weighing device, providing required throughput and readability, is selected and if criteria that are to be fulfilled by the labelling unit are well established. First of all, applied label size must be determined, it is also necessary to specify to which product side the label is to be stuck. Failing to provide detailed information with regard to the above may cause problems concerning weighing instrument operation later on. It may either result with not high enough throughput or with complications when it comes to application of label onto the product.

The wider the knowledge concerning instrument functionality, its intended future use and possibilities, the less probable problems occurrence.

7.7. Automatic Weighing Instruments With Sorting Function

Sorting checkweigher is a special type of high technology weighing instrument enabling weight control. It has been designed to allow separation of products into two or more groups, either according to difference in weight or with reference to settings.
Usually, these are process-performing instruments that separate the weighed products into respective weight classes. Most often they are used on poultry processing lines and in fish plants.

Fig. 90 Sorting DWM xxx S checkweigher

RADWAG offers two versions of sorting checkweighers:

- an instrument equipped with 6-chute workstation,
- an instrument equipped with 12-chute workstation.

The products can be sorted continuously and until declared threshold is reached - in both cases the quantity of products qualified to a given sort group is not controlled.
However, the operator is provided with a possibility to declare quantity or weight value of raw product which is to be accepted as one sort group. For such an instance the automatic weighing instrument counts or sums particular sorted product, when the declared value is reached the sorter shuts down and respective information is sent to the operator. His task is to empty the station (i.e. to replace the filled-in box with a new one) and register this information in the system. This solution requires at least two sorting stations for one and the same product type (or weight group). When the first one gets shut, the products must fall into the second, i.e. the unblocked one. In such situation special buffers storing the products temporarily are used, the buffer gets blocked at the moment of shutting the first sorting station and the products falls into the buffer where they are stored until the box full of product is replaced with an empty one.

Sorting checkweighers with high throughput can carry out work of few or over a dozen operators sorting products manually by means of a non-automatic weighing instruments.

7.8. Rejection Systems

Choosing the right automatic weighing instrument enabling control of weight, and optionally performing detection of contaminated products, is one of the most problematic issues when trying to decide which device suits particular company requirements the best. Another dilemma is appropriate system of rejection of defective products, guaranteeing that only perfect goods will go to the warehouse.
Apart from proper rejection mechanism it is necessary to ensure correct operation of the system regardless of breakdowns that unfortunately are unavoidable on a production line, e.g. pressure drop in the compressed air system, rejecter failure or bin overload.
While designing the system it is necessary to take into account the following:

- product mass,
- dimensions,
- packaging type,
- product type (crisp, hard, fragile etc.).

Rejection systems can be divided into four groups with regard to the method of operation:

- Rejection carried out using compressed air. Such system operates on the basis of nozzle of particular design by means of which the product is blown. It may consist of one, two or more nozzles operating simultaneously. It is mainly applied on production lines where light, short products are weighed which due to the height cannot be rejected using actuator's arm; e.g. spices packed into thin packaging or dried fruit packed into doypack.

Fig. 91 ***Rejection system using compressed air***

- Rejection carried out using pusher, pusher arm ejects parallel to transferred product direction. System of this type can be used in weighing instruments characterised with high throughput, however it has one drawback, the product may get broken in the course of rejection.

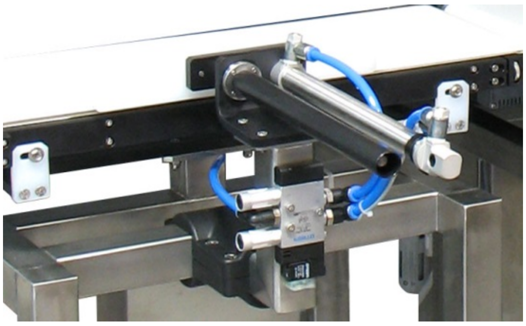


Fig. 92 ***Rejection system using pusher***

- Rejection carried out using arm that grabs the product. This is a relatively safe method of rejection, applied mostly in meat industry. The only drawback here if unsatisfactory throughput. Due to slow product transfer it is used for throughput of up to 100 pcs/min.

Fig. 93 ***Rejection system using arm grabbing the product***

- Rejection carried out by means of lowering the conveyor which is done in order to place the defective product below the transporters. Such system is applied for processing of unpacked products or on multi-conveyor production lines.

Fig. 94 ***Rejection system based on conveyor level change***

Rejection systems are often equipped with storage bins or storage area intended for defective products. Alternative solution are conveyors taking the rejected products away. Storage bins may get overfilled with out-of-tolerance products, to prevent such situation bin overload sensors are used. Breakdown is signalled at the very moment of overload detection, the weighing instrument stops and respective message is displayed. Similar procedure takes place in case of rejection systems featuring either sensor for pressure drop or sensor for product drop control. The former sensor uninterruptedly controls pressure, when it drops below the minimum permissible limit then respective information is immediately sent to the control system. The later sensor checks whether product considered to be faulty has been in fact rejected or not.

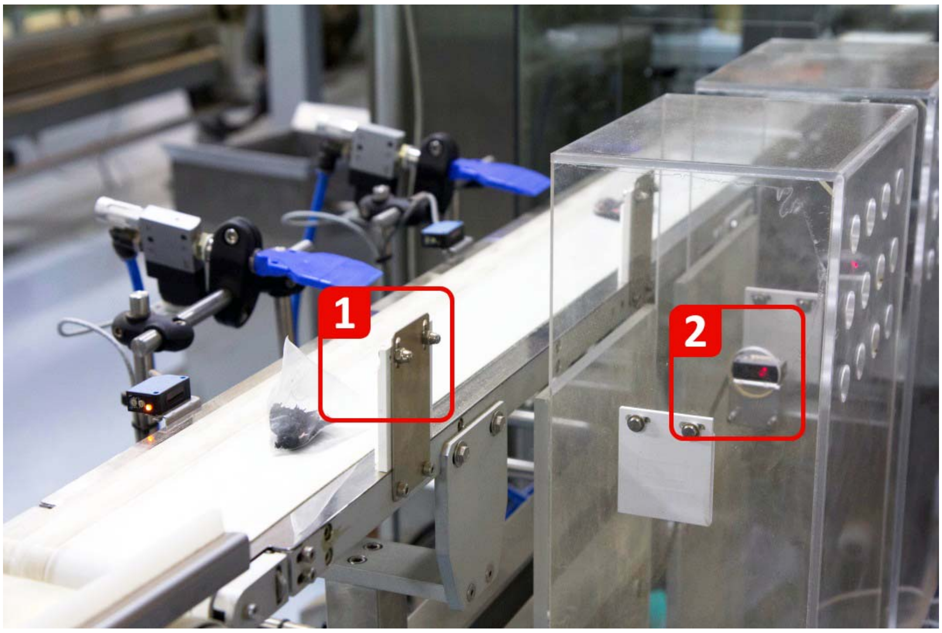


Fig. 95 Rejecter sensors

where:
1 – product drop control sensor
2 – bin overload sensor

All the discussed systems have been designed to guarantee correct operation, their primary function is to prevent out-of-tolerance products from entering the warehouse.
The only thing that cannot be controlled via the automatic weighing system is the personnel. Mistakes of human origin may occur by accident. Due to this storage bins with defective products are often lockable and can be emptied only in presence of authorised group of employees. This kind of practice is necessary especially in case of products contaminated with metal. With regard to danger resulting from metal contamination HACCP strongly recommends use of lockable bins for storage of rejected products.

7.9. Non-standard Functions

Since automatic weighing instruments for single loads carry out 100-percent control they are a good source of information for product engineering or product processing department and for the managements team. Due to the fact that they store numerous data, they enable making complex reports and summaries. With analysis of the obtained results it is possible to specify what is the percentage of out-of-tolerance products or

Fig. 96 Automatic barcode scanner

product giveaway and as a result to estimate loss. Moreover one can easily find out about downtimes and check when exactly did they occur, more precisely, on which shift. Statistics reports enable assessment of work results of particular crews and shifts.

On the list of advantages of automatic weighing instruments there is possibility of cooperation with packing machine, this is especially important due to the fact that in the course of such cooperation feedback information is provided.

The weighing instrument while checking dose size can introduce correction and thus optimize filling operation which brings loss reduction. Such system operates as follows: in the course of weighing the scale checks whether successive packages are not too heavy or too light. If overweight or underweight packages get detected then message enforcing entering appropriate correction value is sent to the dosing unit. The weight is controlled and the corrections are entered till the end of the manufacturing process. It is an ongoing process.

The instrument offers option of control of emergency states of packing machines. In case of detection of defective series comprising products with out-of-tolerance mass the line is stopped. This enables immediate reaction of the stuff and prevents significant losses resulting from inaccurately performed packing operation. When speaking of production line with high throughput, the failure of the packing system means huge number of out-of-tolerance products that have to be manually unpacked and repacked.

Systems designed to control collective packaging are based on cooperation between the automatic weighing instruments and labelling and printing systems, this enables marking of a great number of particular cartons. Such solution is a kind of protection preventing potential shortage, it also stops dishonest wholesalers, who partially empty the cartons and next make complaints, from unfair practice. Upon registering the complaint the manufacturer can easily check whether mass of the claimed carton corresponds with the weight value that was printed on it in the course of the packing process. Discrepancy leads to a conclusion that the carton must have been emptied after the packing process end. The label makes it certain that the claimed carton contained all packs when leaving the production line and that no shortage could have occurred in the course of packing.

Automatic weighing instruments offer another one useful functionality which is an effect of combination of automatic scales, scanners and devices measuring product volume.

Systems of this kind usually operate on assorting lines installed in sorting rooms of shipping companies.

Such system enables simultaneous performance of identification of transported carton, determination of its mass and measurement of its volume. Additionally it allows to specify whether measured product shape is regular or irregular, i.e. whether it can be packed easily. This detailed set of information is sent to a central database, where decision on charges is made. Such systems are extremely expensive, however with complete product verification the return on investment is quick.

The above presented functions do not reflect the whole range of automatic scales possibilities, these instruments offer abundance of advantageous options. The scales equipped with operation systems and industrial computers enable practically unlimited configuration and communication possibilities when it comes to cooperation with production line devices.

7.10. Intended Use of Automatic Weighing Instruments for Single Loads

Automatic weighing instruments for single loads are the most commonly used automatic weighing systems. They are generally used in food industry and at any plants where the law-accordant pre-packaged goods control is performed. These instruments are present on automatic and semi-automatic lines and also at workstations where products are packed manually.

Automatic scales are not less frequently met in pharmaceutical industry, however in pharmacy their intended use has a bit different nature. Here they are mainly used for the purposes of control of blister packs (to check whether no pill is missing) or the packaging content (to check whether the information leaflet has been attached).

Automatic weighing instruments have served with the above functions for many years. Presently they are found to be useful also in other areas of industry. It is an effect of constant need to improve manufactured goods quality and ongoing attempt to eliminate defective products. Speaking of furniture industry for example, quite common need is weight control of pack containing furniture accessories (bolts, hinges, handles, knobs). Such pack comprises huge quantity of tiny components which due to different weighs cannot be inspected with use of counting instruments. As for manual control methods, they are time-consuming and do not eliminate latent human errors. In automotive industry the automatic solutions carry out inspection of quality of parts cast from plastic, correctness of wire harness, condition of manufactured joints etc., in metallurgical industry they control quality of manufactured castings.

Areas such as transport and logistics, both developing rapidly, also use automatic weighing instruments for determination of weight, in this case mass of transported parcels is controlled. Weighing systems installed in shipping companies do not aim to control parcel weight but to determine it for the purpose of calculation of charges for the offered services. The particular weight value is first recorded and next sent to the computer system.

There are plenty of examples with regard to atypical applications of automatic weighing instruments for single loads. Each single product can be controlled and its weight measured using such scales. All that needs to be done is just designing a respective technology.

8. E2R System – Computer Supervision System

Rapid technological development, products manufactured in batches and strong competition caused reorganization of industrial plants, which nowadays operate on the basis of automation, and perform carefully monitored production processes. This calls for urgent need to use controlling tools, i.e. weighing equipment designed to store all the generated data. With regard to the above the conclusion is simple, even the most accurate weighing systems remain unnoticed on the market if they do not cooperate with a multifunctional computer systems designed to establish communication with weighing terminals and also to process all acquired data.
With many years of experience in launching and implementing weighing systems RADWAG is able to offer a unique, as far as functionality is concerned, multi-module solution - **E2R SYSTEM** PC software.
Weighing systems operation of which is based on **E2R SYSTEM** software and advanced functions of static and dynamic scales provide countless number of options which are an effect of integration of different programs into one complex tool intended for production and industry.
E2R SYSTEM is a modular, fully integrated software solution intended for companies manufacturing products for the following branches of industry: food, meat, fish, confectionery, chemical, metallurgical and others. Particular modules' functions offer complete support and automation of the manufacturing processes.
There are two main system components: MS SQL database and computer software operating in the computer network and cooperating with the weighing instruments program. No restrictions regarding quantity of operated weighing instruments or computers with activated software are imposed. System-cooperating scales can work temporarily without server support which means that failure of the master computer or network infrastructure does not have to mean abortion of the manufacturing process. Upon restart all locally saved data get automatically synchronised.
It must be said that **E2R SYSTEM**, like other **RADWAG-manufactured** programs, is 100 percent Polish invention adapted to both national and international economic reality.
With use of **E2R SYSTEM** operating the instruments on production lines becomes more comfortable, easier and user-friendly.

8.1. Intended Use and Functions

The main aim of **E2R SYSTEM** is complex real-time support of both integrated and individual weighing systems.
Weighing system based on **E2R SYSTEM** program can be placed and used in an office, directly on-site in the production hall, also in conditions not intended for a regular PC computer, this is due to the fact that it operates using specialized weighing terminals.

The standard system tasks include:

- collecting weighing-related data and online record of data in databases,

- local offline buffering of weighings that are being collected, online sending of the collected weighings to the database,
- complete support of weighing processes carried out in accordance with adopted operation schemes,
- synchronisation of data that is being collected with all modules of the system,
- complete integration with production environment and administration system of the company (cooperation with warehouse and accounting programs and with ERP, CRM systems),
- full cooperation with RADWAG-designed weighing programs,
- real-time preview of current status of instruments connected to the weighing system,
- generating advanced reports on the basis of database-stored information.

8.2. Architecture

E2R SYSTEM comprises PC modules, operating as a managing software, and modules intended for weighing terminals, operating as an executive software.
The data registered by the system is acquired directly from weighing terminals' databases, or indirectly from basic terminals or other weighing equipment via one of the modules - **E2R SYNCHRONIZER**.
The system enables online monitoring of status of all system-connected scales, this is with use of app designed for visualisation purposes - **E2R MANAGER**.
Communication of the weighing system with other computer systems can be established using module for data synchronization **E2R MSD**, which module provides transfer of data between the systems.

E2R SYSTEM comprises the following PC software modules:

- E2R Weighing Records,
- E2R Formulations,
- E2R PGC,
- E2R Checkweigher,
- E2R Moisture Analyzer.

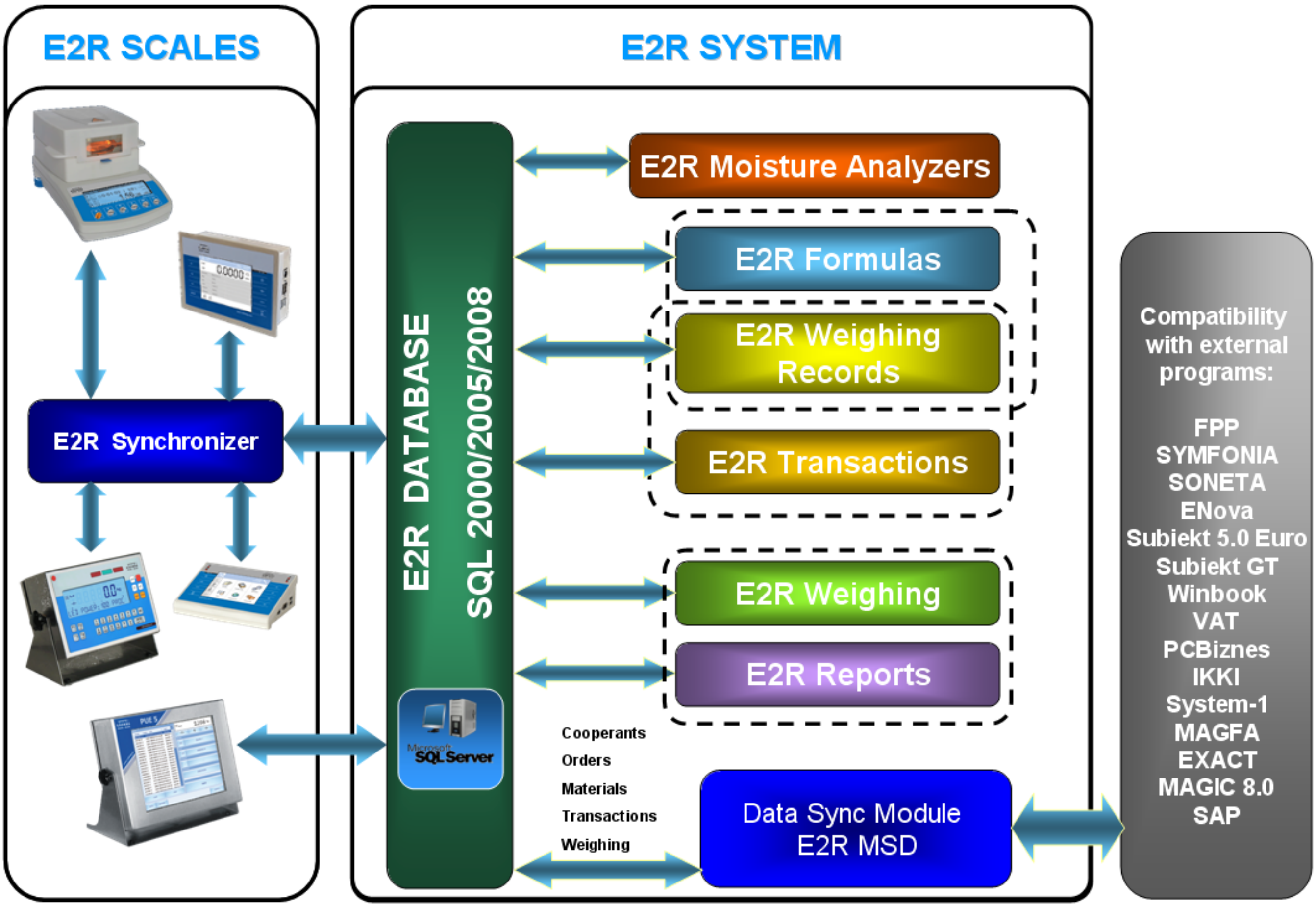
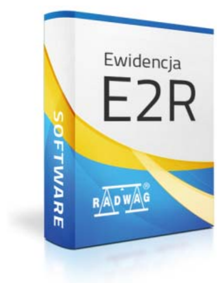


Fig. 97 E2R Architecture

The modules can be installed either separately or in sets, all selected modules concurrently or one by one depending on the particular company requirements. Functions of given weighing systems vary which is conditioned by used modules and the options they offer.

8.3. E2R Modules

8.3.1. E2R WEIGHING RECORDS



E2R Weighing Records module has been designed to register measurements carried out with use of weighing terminals. It may happen that weighings are not related one to another, i.e. they have no common data (weighing records) but still are part of a weighing process with determined start and end (transaction) or of a weighing process where list of particular products that are to be weighed is determined (production order).

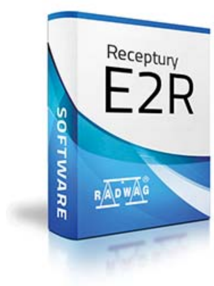
The module enables record of weighings carried out using weighing terminals which are intended to perform quick "+/-" control. With this, operator's role is limited to the minimum. E2R Weighing Records is used in plants with multi-workstation production lines where acquiring large quantity of weighings carried out on many scales over short period of time is required. It is useful also in plants where there is a need to track flow of products, exchange data with an accounting software and settle production.

Basic functions of *E2R WEIGHING RECORDS* module:

- support of databases: Products, Customers, Warehouses, Tares – Packaging, Labels, Operators, Vehicles, Universal variables, Traceability processes,
- record of weighings acquired from network-operating scales in MS SQL database,
- support of transactions,
- support of production orders,
- support of warehouse management,
- record of weighings performed in the course of quick +/- control,
- preview of statuses of system-operating scales,
- free data filtering,
- simplified or detailed reporting,
- generating reports with regard to particular time interval,
- export of recorded weighings to file: PDF, HTML, MHT, RTF, XLS, XLSX, CSV, TXT,
- support of Weighings Archive,
- cooperation with other E2R System modules,
- exchange of data with external programs via Data Synchronisation Module (MSD),
- defining access levels for particular operators,
- cooperation with printers and labellers,
- numerous application skins.

E2R WEIGHING RECORDS module comprises E2R Synchronizer, E2R Manager and E2R MSD programs.

8.3.2. E2R FORMULATIONS



E2R Formulations module enables planning, issuing and carrying out production orders on the basis of created recipes that are stored in formulations database.
Each recipe provides list of ingredients that are to be weighed, weight tolerance for particular ingredient and parameters (stages quantity, batches related data, scale, operator) in accordance with which the formulation is to be carried out.
This module facilitates warehouse management relating to formulation processes, support of E2R System databases and reports on performed production orders.
Supplemented with Terminal E2R Formulations program, it enables dosing particular recipe ingredients with use of one or few weighing platforms, wherein the said dosing operation is controlled by one terminal and accordant with production order parameters.
E2R Formulations module is especially useful in industries such as: construction, food, confectionary, chemical, pharmaceutical, metallurgical and anywhere where dispensing of products or ingredients in compliance with a given recipe is required.

Basic functions of *E2R FORMULATIONS* module:

- support of databases: Products, Warehouses, Tares – Packaging, Labels, Operators,
- record of weighings acquired from network-operating scales in MS SQL database,
- creating recipes,
- managing recipes and orders,
- manual and automated performance of the formulation process,
- dosing up to specified mass,
- multiple recipe performance,
- support of production orders,
- preview of completed production orders,
- support of warehouse management,
- preview of statuses of system-operating scales,
- free data filtering,
- simplified or detailed reporting,
- generating reports with regard to particular time interval,
- export of recorded weighings to file: PDF, HTML, MHT, RTF, XLS, XLSX, CSV, TXT,
- cooperation with other E2R System modules,
- exchange of data with external programs via Data Synchronisation Module (MSD),
- defining access levels for particular operators,
- cooperation with printers and labellers,
- numerous application skins.

8.3.3. E2R PGC

E2R PGC module has been designed to carry out and monitor control of pre-packaged goods. Its main task is to synchronise databases of operators, products and performed controls, it also aims to record measurements carried out on network-operating scales.
The system enables real-time preview of particular scales statuses, with this the control process can be observed. The results are presented either in writing or in a graphic form - as a graph. The operator managing the control can stop it or restart by means of a computer and respective computer interface which features customised access levels.
All data acquired in the course of measurements are first recorded locally, i.e. on the weighing device, next they are transferred to a system database stored on a computer.
E2R PGC module is used in plants where the manufactured products must be monitored in accordance with law on pre-packaged goods.
Like other E2R SYSTEM modules, also E2R PGC is a multi-workstation software that can cooperate with many scales, and be operated on many computer workstations.

Basic functions of *E2R PGC* module:

- support of databases: Products, Operators, Controls,
- record of weighings and controls acquired from scales connected to the weighing system,
- control of pre-packaged goods carried out in accordance with law specified criteria,

- control of pre-packaged goods carried out in accordance with internal criteria,
- different control types: with average tare, empty - full, full - empty,
- possibility to assign a given product with particular parameters and control types,
- defining access levels for particular computer/scale program operators,
- preview of weighings and controls saved to a database,
- preview of statuses of system-operating scales,
- free data filtering,
- simplified or detailed reporting,
- generating graphs on the basis of the recorded data.

8.3.4. E2R CHECKWEIGHER

E2R Checkweigher module has been designed to enable cooperation of E2R SYSTEM with dynamic scales manufactured by RADWAG. It facilitates both record of completed measurements into a computer database and performance of PGC control.
The module is mostly applied in plants where quick weighings or PGC controls must be registered using dynamic scales, e.g. in food, meat, fish, confectionery or chemical industry.
Like other E2R SYSTEM modules, also E2R CHECKWEIGHER is a multi-workstation software that can cooperate with many scales.

Basic functions of *E2R CHECKWEIGHERS* module:
- support of databases: Products, Operators, Controls,
- collecting weighings stored by dynamic scales,
- computer-performed preview of weighings,
- possibility to sort the colected weighings by set filters,
- possibility to operate large quantity of weighings in real-time,
- defining access levels for particular operators,
- generating general and detailed reports on the basis of collected weighings,
- generating graphs on the basis of weighings carried out within a particular time interval,
- generating PGC or standard reports,
- preview of status of dynamic scales connected to the weighing system,
- generating weighings graph for a given scale in real time, controlled product parameters are taken into account,
- possibility to enable or disable collecting of single weighings and generating reports on them, option depends on hardware configuration of the computer on which E2R Checkweigher program is installed.

E2R Checkweigher module comprises *E2R Synchronizer* and *E2R Manager* programs without which acquiring data from dynamic scales connected to E2R system would not be possible.

8.3.5. E2R MOISTURE ANALYZER

E2R Moisture Analyzer module has been designed to enable record of weighings carried out on RADWAG-manufactured moisture analyzers which when operating in a network form weighing system for control of manufactured products humidity.
Recorded data facilitate generating reports and graphs on the basis of completed drying processes. The operator can use one of many available templates.
E2R Moisture Analyzer module is a solution particularly used in laboratories but also in industry. In plants the module supports current monitoring of the final production process. *E2R Moisture Analyzer* is indispensable wherever preview, analysis and archiving of drying processes carried out using RADWAG moisture analyzers is required.

Basic functions of *E2R MOISTURE ANALYZER* module:

- support of databases: Products, Operators, Dryings,
- readout of data generated by moisture analyzers and record of the data to a database,
- online operation facilitating preview of drying processes parameters,
- display of current information on process status, carried out using a computer,
- online generating of graphs with regard to drying time,
- display of final information on the drying process result,
- access to reports generated by moisture analyzers,
- automatically activated connection, upon running the computer, between moisture analyzers and a weighing system,
- possibility to connect moisture analyzers to a weighing system via RS 232 or Ethernet,
- generating reports on completed dryings in accordance with set filters,
- possibility to present archive results saved to database,
- defining access levels for particular users,
- customization of graphical interface layout.

8.4. Exemplary Installations and Implementations

8.4.1. E2R WEIGHING RECORDS

One of the most complex installations operating on the basis of *E2R WEIGHING RECORDS* is weighing system implemented in Espersen company - a world leader processing frozen blocks of fish fillets and frozen breaded fish products.
Espersen Polska Ltd. located in Koszalin employs about 1000 people and it is one of the largest fish processing companies operating on the Polish market. Its main goal is to be the second-to-none codfish supplier in the country. This means both strict requirements regarding the manufacturing process and high demands put forward to the counterparty providing solutions enabling Espersen to reach the aforementioned ambitious aim.

This weighing system was implemented mainly to monitor production throughput, reduce costs and to settle piecework members.
The below diagram presents production process supported by E2R system.

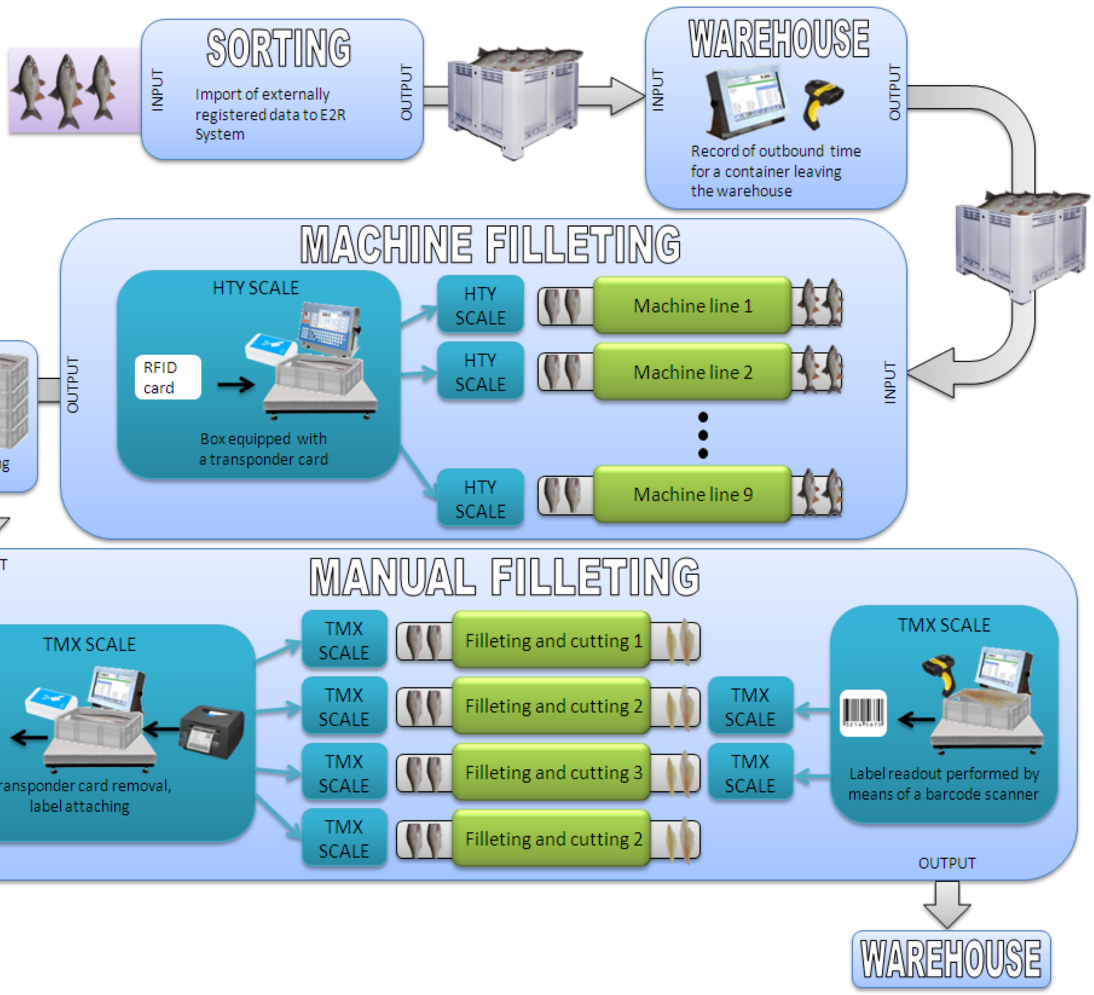


Fig. 98 Diagram of weighing system implemented in Espersen company

The implementation process was divided into stages in order to make transfer from manual product registration to registration by weighing terminals safe and businesslike.
First the weighing system was installed and implemented in the most critical point of the production process, the manual filleting line. It was necessary to computerize the registering method as fast as possible. This brought an immediate positive result:

- low production cost guaranteed by right control and effective use of human resources,
- improved throughput due to piecework,
- quickly generated precise reports,
- simplified decision making process due to precise and on-time data analysis,
- possibility to draw up work schedule and to record work time of operators.

The next implementation stage covered installation of the weighing system in departments where sorting, storing and machine filleting, preceding manual filleting process is carried out. Implementing the system in the said departments brought considerable benefits resulting form:

- monitoring of raw material loss (water draining, fish bone removal),
- downtimes reduction,
- on-time production,
- shorter raw material storing (fast inventory turnover),
- better material management,
- much less significant loss being an effect of surplus stock (capital freeze, storage costs, lower quality),
- coordination of all production resources; instruments, software, materials.

The system operates on a production area, and it can work in conditions not intended for a regular PC computer, this is due to application of specialized weighing terminals manufactured by RADWAG. Data registered by the system is transferred directly or indirectly from the weighing workstations and saved to virtual SQL server located in the server room.
The system may comprise any quantity of computer workstations that may serve as managing and reporting tool. Each workstation facilitates online monitoring of the status of any scale operating in the system.

8.4.2. E2R FORMULATIONS

Good example of a weighing system operating on the basis of *E2R FORMULATIONS* program is the installation implemented in NUTRICIA - a dairy plant located in Krotoszyn. NUTRICIA subsidiary manufacturing dairy products in Krotoszyn is a branch office of NUTRICIA Polska, which makes it a member of DANONE Group. It offers raw materials and semi-finished products for modified milk and baby cereal along with high quality dairy food. The plant implemented HACCP Quality Control System, which was approved among many due to application of RADWAG weighing system.
E2R FORMULATIONS program was implemented mainly because of a demand for detailed control of the formulation process, which control would allow to eliminate potential human origin mistake in the course of dosing the recipe ingredients. 100 percent control of the manufacturing process allowed to boost the weighing system functionality, as a result all IT systems operating in the plant were integrated into one. The final version of the system processes data acquired form laboratory, weighing area and control area, divided into two independently working systems, where the formed mixture is checked.
The below diagram presents production process supported by E2R system.

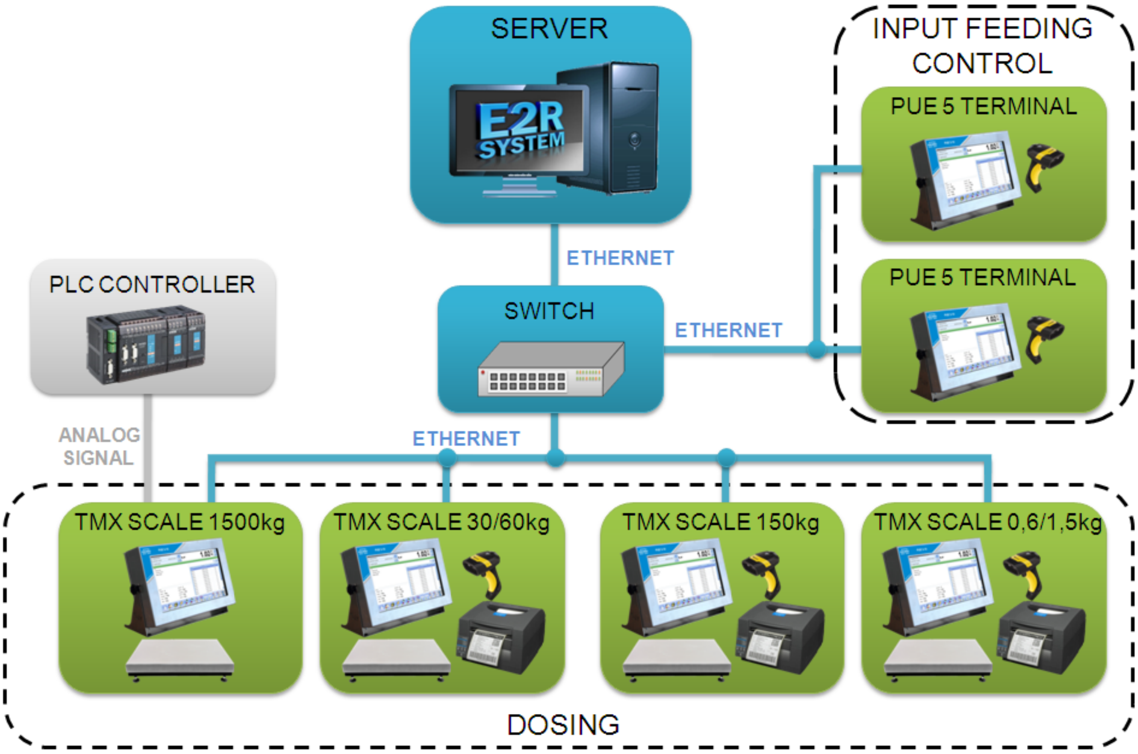


Fig. 99 Diagram of weighing system implemented in Nutricia company

The weighing system comprises TMX workstations, equipped with a weighing platform or a barcode scanner and an automated system controlling feeding hooper valves. The system is presented in the photo below, on the left there is a weighing workstation designed to perform dosing, on the right there is a workstation for control of the formed mixture.

Fig. 100 Weighing system implemented in Nutricia company

The weighing system operates directly in the production hall, where the terminals connected via Ethernet with the database server, capture data form other IT systems. It consists of PC modules that manage information and modules installed on weighing terminals which upon receiving respective commands carry out required operations.

E2R Formulations program is responsible for performing the following operations in real time:

- creating and editing recipes,
- importing production orders from an external system and integrating them with recipes saved to an internal formulations database,
- exporting data on completed weighings to an external system,
- previewing competed weighings and production orders,
- generating reports presenting database-saved information.

The above described system brought Nutricia company the following benefits:

- implementation of HACCP Quality Control System,
- monitoring of raw material flow,
- better material management,
- reduction of costs generated by loss being an effect of operators' mistakes.

8.4.3. E2R CHECKWEIGHER

Another example of solution implemented recently by RADWAG is a weighing system operating on the basis of *E2R CHECKWEIGHER*. It has been installed in R. TWINNING AND COMPANY Ltd.

This innovative multi-modular weighing system ensures integration of static and dynamic weighing workstations. It supports the manufacturing process making it automatic and simultaneously provides indispensable product control. For the purposes of this solution, HTY static scales were implemented. Their operation is almost identical like dynamic scales operation, i.e. these instruments similarly to automatic ones, do not require constant intervention of the operator. He only has to select manufactured product type, all other necessary settings are already assigned to it.

The system was mainly developed to enable performance of pre-packaged goods control in accordance with the Law. On a special customer's request the system can save data sent from scales manufactured by some other producer that were purchased because of the need to preserve weighing system cohesion. E2R Checkweigher supports all weighing systems and presents simplified status of all weighing workstations.

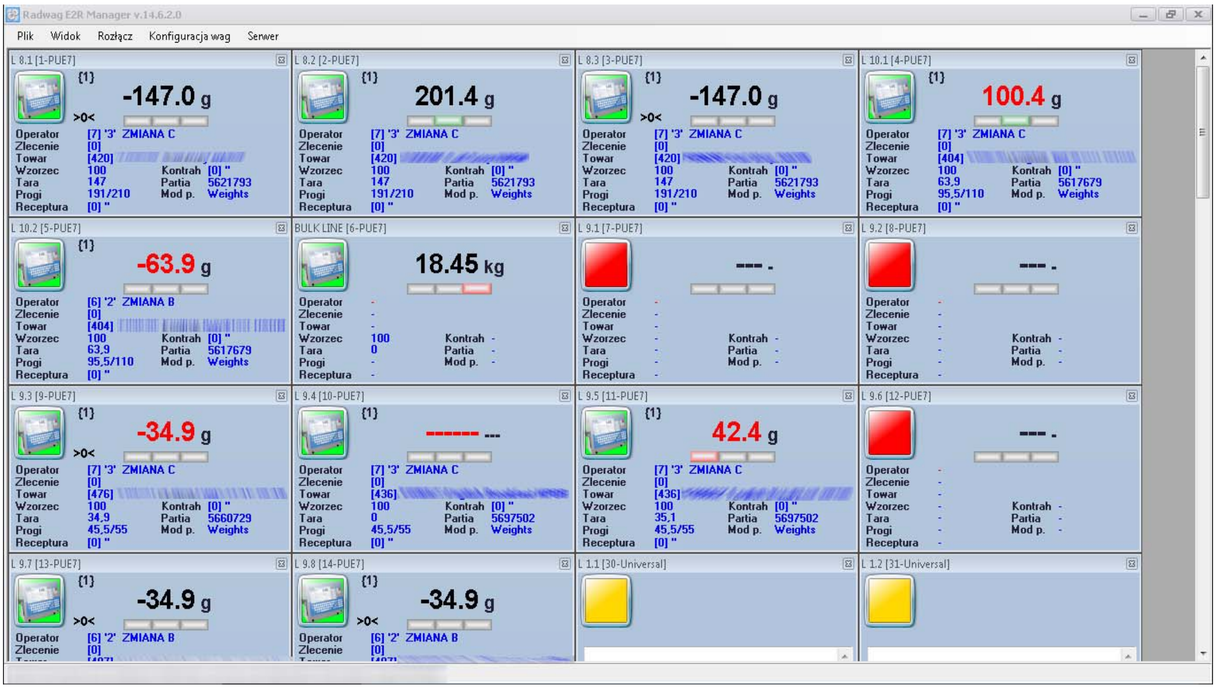


Fig. 101 E2R Checkweigher program - preview of network-operating scales

The system presents detailed information about dynamic scales statuses, which information provides data covering particular time interval, it also shows statistics presenting e.g. distribution of weight and Gaussian distribution.

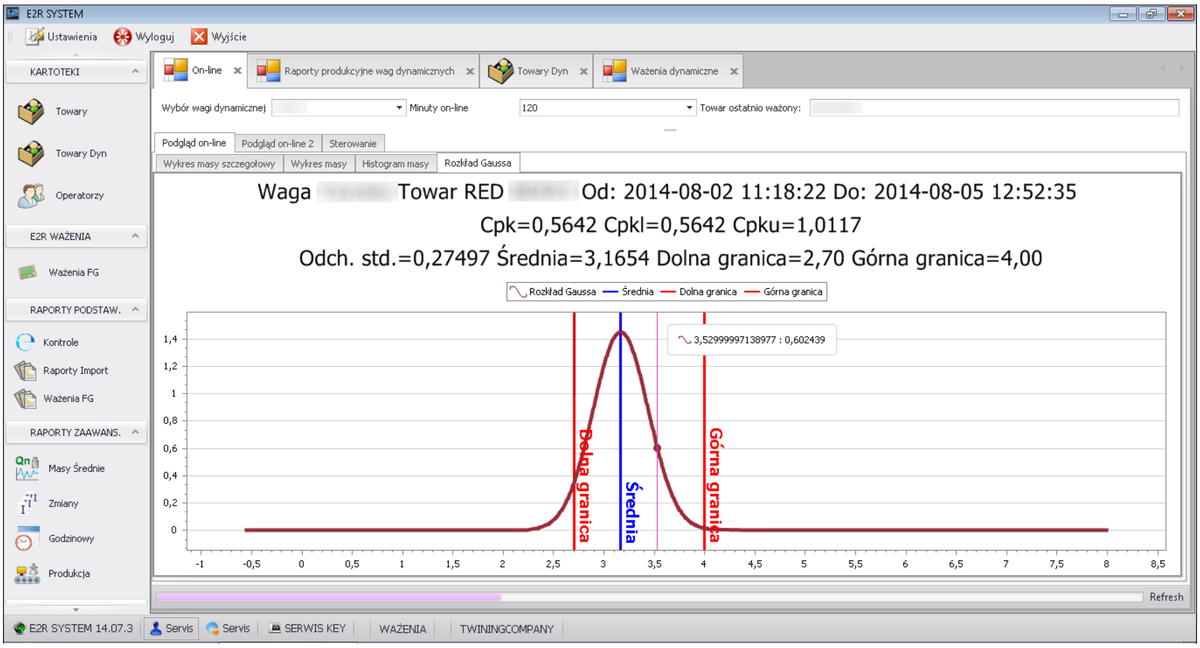


Fig. 102 E2R Checkweigher program - preview of statistics

The system can operate as many devices as necessary, there is no limitation with regard to quantity of supported scales or computers with installed software. RADWAG-manufactured scales can operate for a particular period of time without connection with a server, due to this server or network infrastructure failure does not result with downtimes. Upon server restart all data is automatically synchronized.

Advanced system functions enable to trace the product and to monitor current status of the instruments simultaneously allowing complex analysis and assessment of archive production.

All the information obtained in real time enable immediate recognition of problems and as a result disturbances affecting weighing operation can be reduced if not eliminated. The information provided in the course of the manufacturing process, if not used right away, can be analysed afterwards since the system records and stores all process related data.

An invaluable system asset is a complex report module. Using it the operator can generate different kinds of reports presenting user-selected data.

E2R system is a user-friendly and intuitive tool which can be operated by both experienced and unexperienced users, of course access to particular options requires respective permission levels to be granted.

Production results can be presented in many ways, presentation method depends on scale type and used module. All displayed information compose one coherent image of the manufacturing process course.

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