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AUTOMATIC WEIGHING – PRINCIPLES, APPLICATIONS & DEVELOPMENTS

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Abstract: Automatic weighing plays an important part in many fields of applications: Large quantities of commodities and raw materials are handled in trading centres using automatic belt weighers or totalizing hopper weighers for bulk-to-bulk weighing, smaller quantities of commodities being meant for end users are automatically filled and weighed by gravimetric filling instruments, by catchweighers or checkweighers. Commodities transported on vehicles or by rail are often weighed automatically by in-motion road vehicle weighing instruments or automatic rail-weighbridges, respectively. New developments and measurement techniques are especially observed in the field of waste disposal, weighing of container wagons in cross-border traffic, shovel dozers for weighing building materials, and automation of processes in the food and non-food industry. This paper is intended to give a survey on the state of the art in automatic weighing and on international efforts (eg. OIML) towards harmonization of specifications and test procedures for automatic weighing instruments.

Keywords: Automatic weighing, OIML, weighing instruments

1 INTRODUCTION

National and international trade, commercial transactions and industrial processes today are unthinkable without weighing technology. Weighing technology is no longer confined to simple weighings on stand-alone instruments. Intelligent weighing systems in networks increasingly determine and influence trade and industry by integration of the weight as reference quantity for many processes [1]. Examples are: Counting of small elements on the basis of weight; length determination of extruded products on the basis of cross-section and weight, proportioning of mixtures of bulk and liquid products by continuous and discontinuous weighing.

It is usual to classify weighing instruments into non-automatic and automatic weighing instruments. While non-automatic weighing instruments require the intervention of an operator during weighing [2], automatic weighing instruments do not. They follow a predetermined program of characteristic automatic processes [3]. This paper is exclusively dealing with automatic weighing instruments.

As other measuring instruments, also automatic weighing instruments have developed from purely mechanical stand-alone instruments to electromechanical and electronic instruments which are nowadays microprocessor or PC based, software controlled and capable of communicating with peripheral equipment via digital interfaces.

Already at the end of the 19th century the progressive industrialization called for a higher working speed than could be provided by non-automatic weighing instruments, especially for bulk products like raw material or grain that was loaded into or unloaded from ships. Therefore, the first automatic weighing instruments which received type approval about 1880 have been automatic gravimetric filling instruments, see Fig. 1 [4,5]. They had maximum capacities up to 500 kg and were used for bulk-to-bulk weighing of grain, especially in ports. It is unique that these first purely mechanical gravimetric filling instruments are still manufactured today [5].

Today there is a great variety of different kinds of automatic weighing instruments [4,6]: belt weighers, catchweighers, weigh price labellers, checkweighers, mobile and in-motion vehicle weighing instruments, gravimetric filling instruments, etc. Considering the market value of weighed products, belt weighers, totalizing hopper weighers and checkweighers are most important.

In many countries, automatic weighing instruments require type approval if they are used for commercial transactions. There are a couple of international recommendations of the International Organization of Legal Metrology (OIML) covering the relevant categories and types of automatic weighing instruments [3, 7-10].

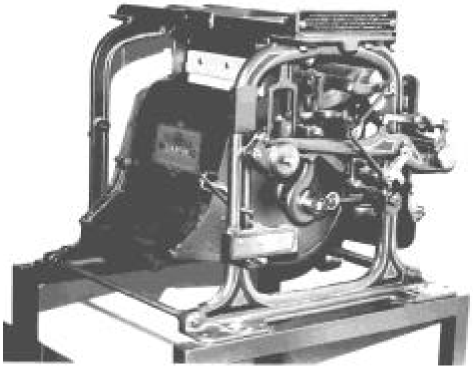


Figure 1. First mechanical automatic gravi-metric filling instrument with type approval in 1883/88, type Chronos G, system C (*Chronos Richardson*)

Meanwhile many countries have taken over these recommendations and have implemented them into national legislation. These recommendations also contain definitions and classifications of automatic weighing instruments that are referred to in this paper.

Sometimes it is difficult to find the exact borderline between a non-automatic weighing instrument and an automatic one, because today also non-automatic weighing instruments show easy operation, very short weighing cycles and quasi-automatic weighing functions, so that the intervention of an operator during weighing is reduced to a minimum. In case of doubt whether a weighing instrument is a non-automatic or an automatic one it is referred to the definition formulated by WELMEC [11].

The following chapters are intended to give a general idea of the great variety of measuring principles and applications of automatic weighing instruments. In addition, new developments and measuring techniques and international efforts towards harmonization and standardization of requirements and specifications are shown.

2 MEASURING PRINCIPLES AND APPLICATIONS OF AUTOMATIC WEIGHING INSTRUMENTS

2.1 Continuous Totalizing Automatic Weighing Instruments (Belt Weighers)

A belt weigher is an automatic weighing instrument for continuously weighing a bulk product on a conveyor belt, without systematic subdivision of the mass and without interrupting the movement of the conveyor belt [3]. Continuous totalizing weighing implies the current measurement of the actual belt load q (in kg/m), the belt speed v (in m/s), the multiplication of q and v resulting in the actual mass flow (in kg/s) and the integration over time of the mass flow, resulting in the mass to be determined (in kg). Thus, belt weighers determine the total mass of a bulk material, most of all coal, ore and other raw material (usually no grain), where normally the method of bulk-to-bulk weighing is applied. The measuring principle and a view of a belt weigher are shown in Figures 2a and 2b, respectively.

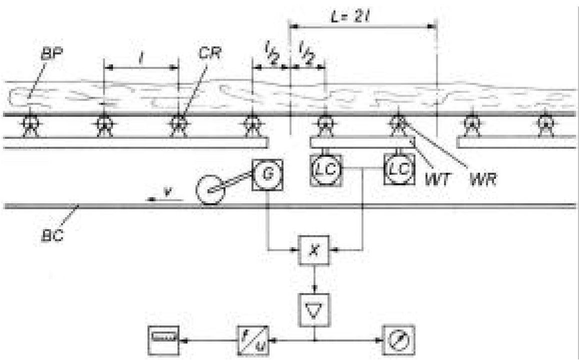


Figure 2a. Principle of a belt weigher [4] **Figure 2b.** View of a belt weigher (*Schenck Process*)
BC belt conveyor, *BP* bulk product, *CR* carrying roller, *G* speedometer, *L* length of weigh table, *LC* load cell, *WR* weighing roller, *WT* weigh table, *X* signal processing

Belt weighers are predominantly used in heavy industry with big mass flows of bulk material, eg. in ports and mines or for opencast mining. Mass flows up to 20.000 t/h can be achieved at belt speeds up to about 5 m/s, and relative uncertainties of about 1% with type approved instruments.

Several variants of belt weighers exist for special applications, among which proportioning belt weighers play the most important part. These allow the setting of a certain mass flow (usually <1500 t/h) by controlling the belt speed (usually <0,5 m/s).

2.2 Automatic Weighing Instruments for Discontinuous Weighing

This is the biggest group of automatic weighing instruments which comprises a great variety of different measuring principles and constructions.

Discontinuous weighing means that the masses of discrete loads are determined in sequence. For bulk material or liquid products this implies that the mass flow has to be divided into separately measurable partial loads that are measured eg. in tanks or hoppers and that are delivered to the bulk after measurement. Weighing instruments which automatically sum up the masses of discrete partial loads are called totalizing hopper weighers. If the mass of each discrete load is determined and used, eg. for labelling prepackaged goods, one speaks of catchweighers.

Discontinuous weighing can either be performed statically, ie. the conveyor belt is stopped during measurement, or dynamically, ie. the conveyor belt is in motion during weighing. In-motion weighing is the preferred method because it allows a much higher speed of operation. "Weighing in motion" can mean both, either that a product, eg. a prepackage, is automatically put on a conveyor belt for being weighed, or that a vehicle itself is crossing a weighbridge for automatic weighing.

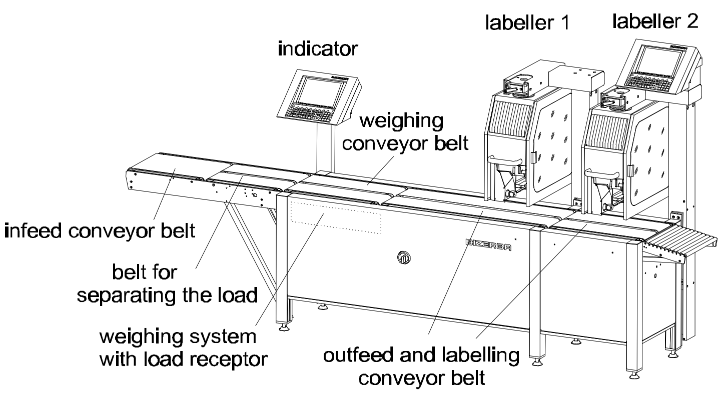
2.2.1 Automatic Catchweighing Instruments (Catchweighers)

A catchweigher is an automatic weighing instrument that weighs preassembled discrete loads or single loads of loose material [7]. The measuring principle is similar to a non-automatic weighing instrument except for the automatic loading and unloading of the load receptor. Catchweighers in the narrower sense are: weigh price labellers, hopper weighers, postal and rate indicating scales, shovel dozers and refuse vehicles with on-board weighing systems. In the OIML recommendation R51 [7] these automatic weighing instruments are classified as catchweighers of category Y. Besides category Y, OIML R51 also mentions catchweighers of category X which are called checkweighers. Checkweighers are used for the special purpose of checking prepackages of the same nominal mass and have special functions. They are not considered as catchweighers in the narrower sense, and are therefore dealt with separately, see Chapter 2.2.2.

- Weigh Price Labeller

A weigh price labeller is an automatic weighing instrument which determines the weight and the price of an individual article, eg. a prepackaged good, and labels the package. The typical set-up of a weigh price labeller is shown in Fig. 3. Weigh price labellers are equipped with several conveyor belts, an indicator and one or more label printers.

Prepackaged food, like cheese, sausage or bottled drinks, are most important for consumers. Therefore the legislation in many countries requires weigh price labellers to be type approved.



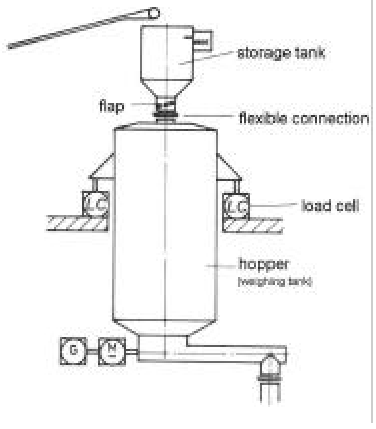


Figure 3. Typical set-up of a weigh price labeller (*Bizerba*) **Figure 4.** Principal of a hopper weigher [4]

- Hopper Weigher

Hopper weighers or hopper scales have a load receptor in the form of a tank or a hopper to take in bulk material or liquid to be weighed, see Fig. 4.

The most important application of hopper scales is the accurate production of batches by weighing the components to be mixed. Building material scales, for instance, weigh components like cement, mortar, sand and water for the production of concrete which is often transported by lorries. Batching systems or multicomponent scales are also used in other important industries like steel and glass production, production of colours and lacquers and in food industry. For each component normally one individual hopper scale is used. Silo scales are especially used for supervising the filling level of silos for bulk materials and liquids. With hopper weighers, relative uncertainties of 10^{-3} and less can be achieved.

- Postal and Rate Indicating Scales

Postal and rate indicating scales are used to determine the postal or freight charge based on the weight of parcels, freight, etc. As a result of the increasing air traffic, especially measuring instruments for determining the "dimensional weight" are getting more and more important, see Fig. 5.

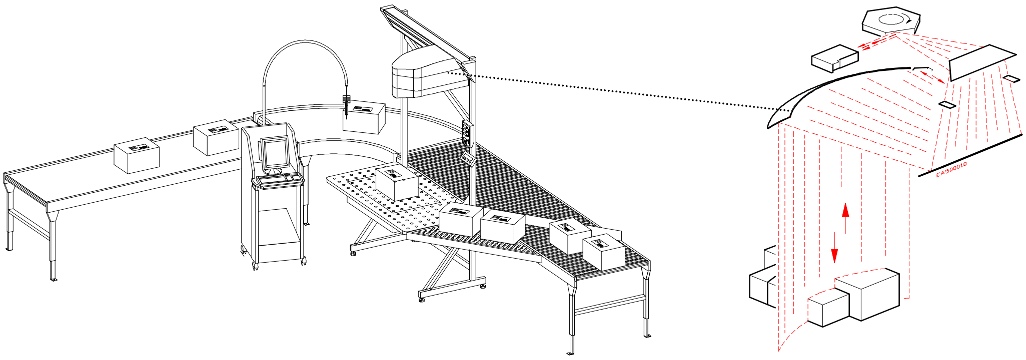


Figure 5. Determination of the "dimensional weight" of parcels by automatic weighing and laser scanning of the three dimensions (*Cargoscan*)

Here the mass of a parcel on the conveyor belt is automatically determined by a catchweigher, whereas the three parcel dimensions are simultaneously and automatically measured by a laser scanner.

- Mobile Weighing

Mobile weighing is quite a new weighing technology and means that the weighing equipment is integrated in vehicles, like shovel dozers or refuse vehicles, so that building materials or waste can be automatically weighed during transport, ie. with both the vehicle and the lifter carrying the load being in motion. This rather new and still developing technology is detailed in Chapter 3.1.

2.2.2 Checkweigher

A checkweigher is a catchweigher that subdivides articles (objects) of different mass into two or more subgroups according to the difference between their mass and the nominal set point (mass) [7]. For prepackaged products of equal weight it is checked whether the actual weight of a package is equal to its nominal net content within the tolerances allowed, and packages outside the tolerances are automatically sorted out. Weighings can be performed statically or in motion. Checkweighers are usually equipped with additional statistical functions, like calculation of mean values and standard deviations, in order to enable a proper control and management of the filling process.

Checkweighers are most important for the production of a great variety of prepackaged products, like food, spray cans and tablets. Fig. 6 shows the set-up and typical components of a checkweigher.

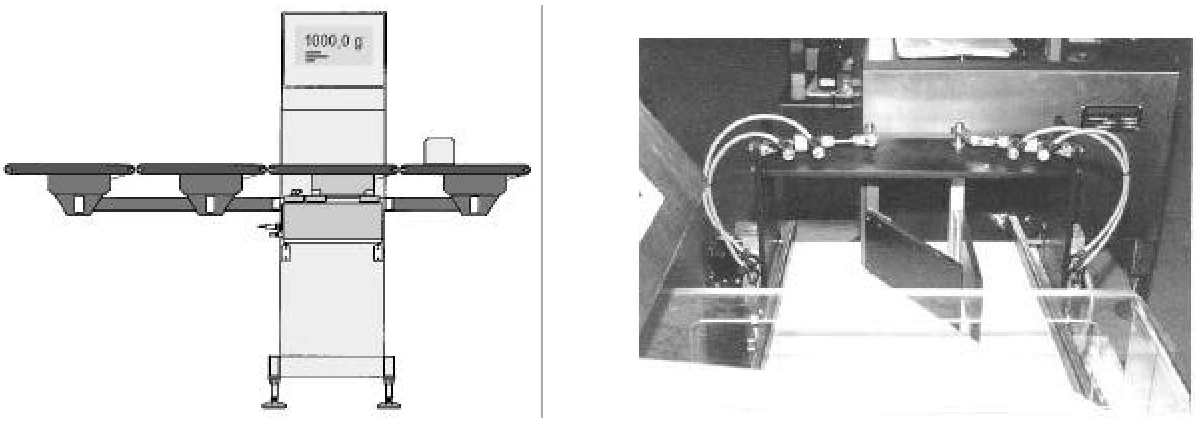


Figure 6. View of a checkweigher (left) with a pusher (right) for sorting out packages (*Garvens*)

The construction is similar to a weigh price labeller, ie. the main components are the infeed conveyor belt, the separation belt, the weighing conveyor belt and the outfeed conveyor belt. Instead of a label printer, however, a checkweigher comprises a device, here a pusher, that sorts out packages outside the tolerances. Checkweighers usually have maximum capacities of less than 100 kg and they achieve weighing rates of 400 packages per minute and more [6]. Relative uncertainties of 10^{-3} and less can be achieved, depending eg. on the belt speed, the mechanical construction, the load cell(s) used and the form and content of the packages.

2.2.3 Totalizing hopper weigher

A totalizing hopper weigher is an automatic weighing instrument that weighs a bulk product by dividing it into discrete loads, determining the mass of each discrete load in sequence, summing the weighing results and delivering the discrete loads to the bulk [8]. Totalizing hopper weighers are used if a better accuracy than that of belt weighers is required. A typical application is the determination of the mass of valuable bulk products, like grain, when they are unloaded from ships in ports. Relative uncertainties of 0,2% and less can be achieved.

2.2.4 In-motion weighing of railway and road vehicles

In-motion weighing with automatic rail-weighbridges and road vehicle weighing instruments is an actually developing technology. It is therefore dealt with in Chapter 3.2.

2.3 Automatic Gravimetric Filling Instruments

Automatic gravimetric filling instruments are instruments which fill containers with a predetermined and virtually constant mass of a product from bulk [9]. They comprise essentially an automatic feeding device or devices associated with one or more weighing units and the appropriate control and discharge devices.

Gravimetric filling instruments play an important part in food and non-food industries, where bulk products or liquids are drawn off from containers, tanks, silos or mixers and put into packages, bags, cans or boxes with predetermined nominal mass. There is a great variety of different products that are filled into prepackages by gravimetric filling instruments: food, grain, milk powder, animal feed, liquids, agricultural products, chemical and pharmaceutical products, building material, etc.. Fig. 7a shows the principal set-up of a gravimetric filling instrument which is capable of performing gross weighings (without discharge container, left) and net weighings (with discharge container, right). Fig. 7b shows a modern high speed bagging line with rotating carousel.

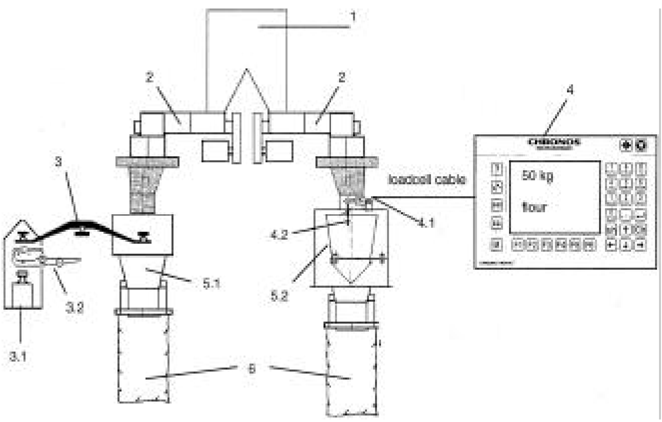


Figure 7a. Principle of an automatic gravimetric filling with instrument (*Chronos Richardson*)

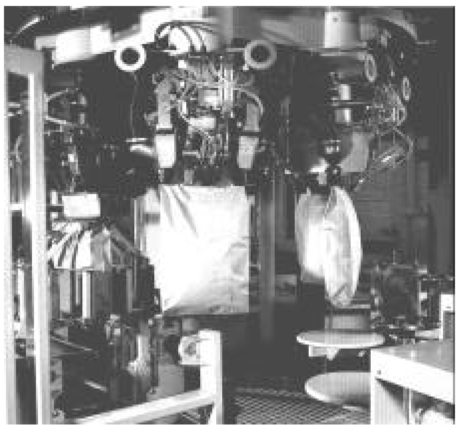


Figure 7b. High speed bagging line rotating carousel (*Chronos Richardson*)

1 weighing hopper, 2 feeding device, 3 weighing instrument, 3.1 weight, 3.2 feed control device, 4 electronic indicator, 4.1 load cell, 4.2 feed control device, 5.1 feed cut-off device, 5.2 discharge container, 6 bag

The feeding device provides a supply of product from bulk to the weighing unit and operates in one or more stages. The feed control device regulates the rate of feed of the feeding device. The fill setting device allows the setting of the preset value which is the nominal mass of the prepackage. The final feed cut-off device controls the cut-off of the final feed so that the average mass of the fills corresponds to the preset value.

Gravimetric filling instruments normally have maximum capacities between 1 kg and 50 kg, but there are also bagging scales for big bags of 200 kg and more. The relative uncertainty of gravimetric filling instruments depends on the mass of the fills. For fills above 15 kg relative uncertainties of 1% can be achieved, while below 15 kg the relative uncertainties are 1,5% to 9%.

According to the different natures and conditions of the filling products there is a great variety of different types of filling and bagging machines, eg. proportioning weighers, differential proportioning weighers, hopper scales or rotor weighfeeders. For granular products or products consisting of pieces, eg. food, also associative weighers are used [6,9].

3 NEW DEVELOPMENTS AND MEASURING TECHNIQUES

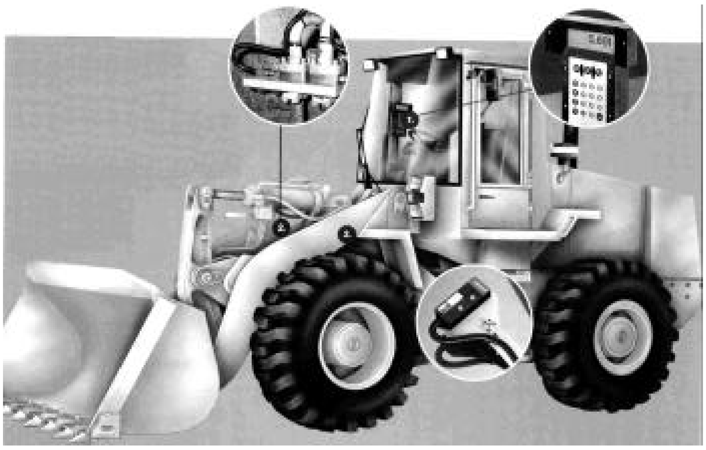
The trend towards automatic weighing is recognized especially in the fields of mobile weighing and in-motion weighing; in addition there is a trend to integrate non-automatic weighing instruments into automatic industrial processes. In the following a short synopsis and some examples are given.

3.1 Mobile Weighing

As mentioned earlier, mobile weighing (sometimes also called "dynamic weighing") means weighing in motion of both the vehicle itself and the product to be weighed during lifting. Considering such critical weighing conditions in addition to the unfavorable environmental influences, it is a remarkable success of modern weighing technology that relative uncertainties of 3% can be achieved with type approved instruments. Vehicles for mobile weighing can be classified as catchweighers of OIML R51 category Y(b) [7].

3.1.1 Mobile weighing with shovel dozers

Shovel dozers are mainly used for handling building material such as gravel, shingle and sand. About 15 years ago the first shovel dozers with on-board weighing systems received type approval in Germany. Mobile weighing offers the big advantage of quick and rather accurate determination of the shovel load; in addition, the operational safety is much improved, because overloading can easily be recognized. Fig. 8 shows a shovel dozer with on-board weighing system.



The weighing system consists of the weight indicator (1), the differential pressure sensor (2) with integrated temperature sensor, and the inductive sensors (3) which define the measuring distance for the integration of the weighing signal during lifting of the shovel.

The maximum capacities normally are between 5 t and 15 t and the scale intervals 50 kg or 100 kg.

Figure 8. View of a shovel dozer with on-board weighing system (*Pfreundt*)

3.1.2 Mobile weighing with refuse vehicles

Waste disposal is of increasing importance in most industrialized countries. In Germany, for instance, waste disposal charges have rapidly increased over the past few years. In order to achieve fair charges, eg. for private households, more and more local governments and communities decide that waste disposal charges should be based on weight. But also waste processing companies increasingly decide to measure the waste by dynamic weighing with refuse vehicles. The first refuse vehicles with on-board weighing systems have been type approved about 8 years ago. In Germany there are currently about 50 type approved and verified refuse vehicles in operation.

The weighing principle is similar to that of shovel dozers; instead of hydraulic pressure sensors, however, strain-gauge or vibrating wire load cells are used. With the latter technique relative uncertainties of about 3% can be achieved for net weights; this corresponds to the

OIML R51 category Y(b). Refuse vehicles always perform two weighings (gross and tare weighing) in order to determine the net weight of a container.

3.2 In-Motion Weighing

As mentioned in Chapter 2.2.4, in-motion weighing with automatic rail-weighbridges and road vehicle weighing instruments is of increasing importance because it offers a considerable reduction in time and costs in the worldwide growing cross-border traffic with containers. On the other hand, it is coupled with lower accuracies due to dynamic and other influence factors. This disadvantage can partly be compensated for by using a larger number of wheel or axle weighing sensors. Both automatic rail-weighbridges and in-motion road vehicle weighing instruments are in prinipal catchweighers, but because of necessary special metrological, technical and testing requirements they are classified in separate OIML recommendations.

3.2.1 In-motion weighing with automatic rail-weighbridges

An automatic rail-weighbridge [10] is an automatic weighing instrument having a load receptor, inclusive of rails for conveying railway vehicles, or weighing sensors that are directly mounted into or applied to the rails. Automatic rail-weighbridges perform in-motion weighings of either a whole train of coupled wagons ("train weighing") or individual wagons ("wagon weighing"); the wagons may be coupled or uncoupled during weighing. The principal of weighing can either be "full draught weighing", ie. wagon weighing with the whole wagon being on a load receptor, or "partial weighing", ie. wagon weighing, where the axles or bogies as parts of the wagon are weighed one after the other on a small load receptor. For legal applications, eg. traffic control, normally both full draught weighing and partial weighing is allowed. For checking of the load distribution of a train also wheel load weighing is applied.

Fig. 9 shows the principal set-up of a modern automatic rail-weighbridge that is capable of performing both full draught weighing and partial weighing, with coupled or uncoupled wagons, with an option of static weighings for higher accuracy demands.

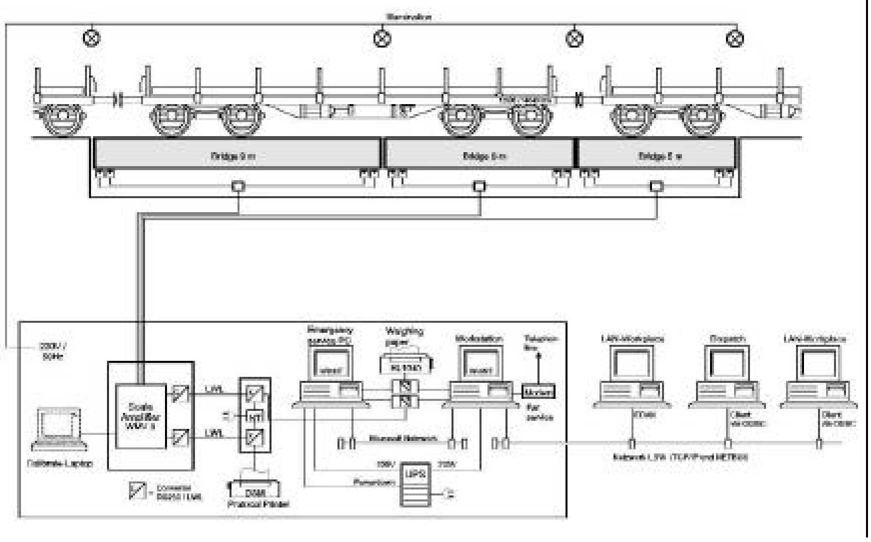


Figure 9. Set-up of an automatic rail-weighbridge with operating and control units for full draught weighing and partial weighing (*Pfister*)

There are different measuring principles possible. Most common are weighbridges that are embedded in the ground, see Fig. 9. But also supplementary installation of special wheel weighing sensors into cavities in the rails are possible, or strain-gauges are directly applied to the rails.

In-motion weighing requires a number of influence factors to be taken into account, eg. dynamic, environmental and foundation influences. Relative uncertainties of 0,5% and less can be achieved if full draught weighing is used or if at least three pairs of properly arranged axle weighing sensors are installed for partial weighing. The maximum operating speed is 10 km/h to 15 km/h, the maximum capacities are about 30 t per axle, ie. 15 t per load cell.

3.2.2 In-Motion Road Vehicle Weighing Instruments

In-motion road vehicle weighing is also a rather young and developing technique. These automatic weighing instruments enable traffic control of road vehicles to be efficiently performed. The measuring principle is similar to automatic rail-weighbridges; however, only axle weighing on small weighbridges which are embedded in the ground, is applied, see Fig. 10.

Figure 10. View of a truck crossing the weighbridge of an in-motion road vehicle weighing instrument (*Pfister*)

For legal applications, eg. traffic control and overload checks, normally type approved and verified instruments have to be used.

At vehicle speeds of 5 km/h up to 10 km/h relative uncertainties of 1% can be achieved. For higher accuracy demands static weighings with non-automatic weighing instruments have to be performed.

3.3 Automatic Weighing in Industrial Processes

Today weighing technology and weighing systems are increasingly integrated in automatic industrial processes. Two examples are given in the following.

- Pharmaceutical laboratories

Non-automatic precision balances (OIML R76 class II, relative uncertainty $<10^{-4}$ and less) are often combined with robotics for automatic handling and weighing of test tubes. Other applications of automated precision balances are formula weighing and statistical checks during tablet production with up to 100 pieces per second.

Besides rationalization, the automation guarantees the compliance with quality assurance and GLP standards.

- Car Industry

Air bags are produced in fully automatic assembly lines. Automatic weighing plays an important part for quick and accurate in-process checks of gas generators. They check the completeness of mechanical parts, eg. screws, and the correct filling of the reaction chamber with fuel pellets or gas.

4 INTERNATIONAL HARMONIZATION OF SPECIFICATIONS AND TEST PROCEDURES

In the field of metrology, harmonization has two aspects:
1. The international adaptation of common requirements (specifications) for measuring instruments.
2. The agreement on and application of the same test procedures for checking the conformity with the requirements.

The aim of harmonization in both cases is the reduction of technical barriers to trade and the realization of a free market for comparable products that are certified according to the harmonized specifications. For automatic weighing instruments the harmonization of both specifications and test-procedures has made good progress for many years through the work of the OIML technical committee TC 9/SC 2. With the five OIML recommendations for automatic weighing instruments [3,7-10] the highest possible metrological standard has been internationally defined for legal applications. Specifications, error regimes and accuracy classes shall not be detailed here. It is rather referred to other publications [12,13] and the OIML recommendations themselves. Many countries have joined the OIML certificate system [14], especially for non-automatic and automatic weighing instruments, and have implemented the OIML recomendations into national legislation already.

In addition, most European countries have signed a Type Approval Agreement for automatic weighing instruments under the umbrella of WELMEC, the European Legal Metrology Cooperation [15]. Technical aspects of automatic weighing instruments are dealt with in Working Group 2 of WELMEC. Currently a new WELMEC guideline for checkweighers and catchweighers is under preparation.

For applications outside legal metrology it is mentioned that automatic refuse vehicles are eg. dealt with in the European committee CEN/TC 183 "Waste Management". Working Group 3 "Identification and Weighing" of this technical committee has started its work only a few years ago and there are no official papers available yet.

In-motion road vehicle weighing instruments are dealt with in OIML TC 9/SC 2 for legal applications and by the Co-Operation for Science and Technology (COST) for applications outside legal control. Since 1995 COST has organized three conferences. Except for predrafts, official specifications, recommendations or standards are not yet available from both OIML and COST.

5 CONCLUSION

Automatic weighing is increasingly important in trade, commercial transactions and industrial processes. There is a great variety of different measuring principles and applications of automatic weighing instruments. The international harmonization of specifications and test-procedures has made good progress thanks to the work of OIML and the publication of five OIML recommendations for all relevant automatic weighing instruments with the exception of in-motion road vehicle weighing instruments.

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