MASS MEASUREMENT FOR METAL ACCOUNTING IN MINERAL PROCESSING PLANTS

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ABSTRACT. In the course of mass and metal balancing in mineral processing plants, the mass measurement of particular products which are part of the evaluation process of the operation efficiency of the technological operations has a significant role. Unfortunately, accurate mass measurement is often overlooked, both in primary design and in subsequent operation, and this leads to compromised results and conclusions. This paper focuses on the most common methods for mass measurement in the mineral processing plants, as well as on the types of weighing equipment, their design features and operation characteristics. Some important aspects of mass measurement are also discussed, e.g. sources of error, calibration methods, and requirements for the correct mass and metal accounting.

Keywords: mass measurements, metal accounting, errors, calibration

ИЗМЕРВАНЕ НА МАСИТЕ ЗА ОТЧИТАНЕ БАЛАНСА НА МЕТАЛА В ОБОГАТИТИТЕЛНИТЕ ФАБРИКИ

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РЕЗЮМЕ. При отчитане на масовия и металния баланс в обогатителната фабрика, основна роля заема измерването на масите (теглата) на съответните продукти, участващи в изчисляване ефективността на работа на заложените технологични операции. Акуратното измерване на масите е много често пренебрегвано, както при първичното проектиране, така и при последващата експлоатация, което довежда до компрометирани резултати и заключения. Настоящата разработка се фокусира върху най-разпространените методи за измерване на масите в обогатителните фабрики, както и върху видовете измервателни уреди, техните конструктивни и експлоатационни особености. Разгледани са и някои важни аспекти при измерване на масите, като източници на грешки, методи за калибриране и изисквания за коректното отчитане на масовия и металния баланс.

Ключови думи: измерване на масите, баланс на метала, грешки, калибриране

Introduction

In literature, metal accounting is defined as a system whereby selected process data is collected from various sources, including mass measurement and analysis, and transformed into a coherent report format that is delivered in a timely fashion in order to meet specified reporting requirements (Morrison et al., 2008).

As reported by Gaylard et al. (2014), in the mineral processing industry, reliable metal accounting is essential to sound corporate governance and it is also becoming a focus of increased attention and concern, particularly as the figures generated by the metal accounting system feed directly into the financial accounts of mining companies. Mass measurement, sampling, and analysis provide the input data for the metal accounting system. Sound corporate governance requires that the procedures used be based on best practice and that the data generated be accurate and handled correctly, transparently, and consistently to produce the accounting reports.

It is also important to give an appropriate definition of mass balancing as a valuable aspect of metal accounting and reconciliation: this is the process whereby input and process streams, or the individual components of the streams, stocks and in-process inventory are measured, sampled, and analysed in order to calculate the mass of each and reconcile the output to the input, plus or minus the stock change.

It is worth mentioning some of the commonly used terms in the field of mass measurement. Authors such as Morrison et al. (2008) suggest the following terminology:

Belt Scale/Weigher – A mass measurement device that continuously integrates and records the load on a belt while it passes the suspended scale or the measuring section of the belt;

Bin Scale – A bin that is fitted with load sensors or other mass detecting devices and has been calibrated so that the weight of the contents can be established and weighed on a continuous or batch basis;

In-Motion Weighing – The weighing of objects that are in motion. Usually applied to rail or road trucks;

Platform Scale – A compound lever scale whose load-receiving element is a platform that is supported by four or (rarely) more main bearings;

Weighbridges – Weigh scales designed to weigh road trucks or rail wagons where the lever system is usually below ground in a pit so that the vehicle or rail wagon can pass over and stop on the scale. In a large capacity, the scale also refers to the structural frame carried by the main bearing which supports the load-receiving element.

Weigh Idlers – Idlers positioned in the weigh carriage assembly so that they sense the weight of the material on the conveyer and transmit the weight through the carriage to the load sensor.

According to Morrison et al. (2008), the primary goal of mass measurement for metal accounting is to establish the mass of the particular material or component present at a specific time, or the mass flow of that component over a defined time period, with a defined accuracy suitable for mass and metal balancing.

Mass measurement can be classified into: measurements that are necessary for custody transfer and primary accounting of the input and output streams to a plant or operation, and measurements that are required for secondary accounting, or management control (Wortley, 2009).

In his introduction, Wortley (2009) describes some of the essentials for any mass measurement system which should be followed if we want to achieve reliable results for primary metal accounting:

- Selection of the most suitable stream and location for measurement;
- Correct specifications and selection of the method and equipment to suit the application;
- Optimum design, location, and installation to permit measurement and calibration by recognised techniques;
- Regular calibration by approved techniques and procedures and certification in the case of custody transfer applications;
- Record keeping and logging of all calibration results, corrections, and readings in order to facilitate error detection and statistical analysis in order to enable the accuracy/precision of the measurement to be calculated;
- Cleanliness, good housekeeping, and maintenance.

The first three requirements should be incorporated into the design of the plant. This is often not the case and thus modifications to existing plants may be required with associated costs and, in some cases, they may be difficult to achieve. However, the latter three are totally under the control of the existing management and are basically part of good management practice.

In mineral processing plants, the mass measurements are usually accomplished using:

- Platform, truck, and rail weighbridges;
- Weigh tanks, hoppers or bins;
- Conveyer belt weighers;
- Flow meters (volume and mass measurement).

The mass measurements could be carried out in rail cars or road trucks, in bins, hoppers, drums, tanks or other vessels, on conveyer belts or in conduits, as well as in open channels. The mass of bulk commodities is usually measured in ships or bulk carriers.

Some of the most common problems related with the mass measurement techniques for metal accounting are as follows: design and equipment selection; record keeping; certification and calibration; plant management and housekeeping.

Methods of measuring mass

Static weighing

According to Gaylard et al. (2009), the road/rail weighbridges (Figure 1) and platform scales are the most accurate form of mass measurement as there are no dynamic effects and they can be easily and frequently checked in operation by the use of internal check weights.

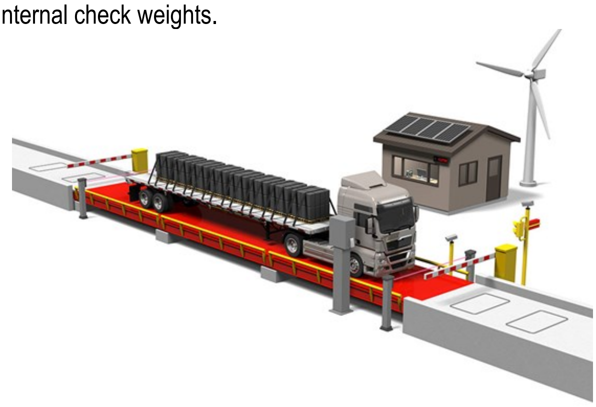


Fig. 1. View of Avery Weigh-Tronix weighbridge (Avery Weigh-Tronix Ltd.)

The mass measurement by truck/platform scale is usually performed by weighing the mass of the truck while it enters the plant area empty and when it leaves fully loaded. Truck scales are a practical solution for mineral processing plants with huge production volumes and constant material flow out of the plant through trucks. They are used particularly if the end products are stored in the plant area and transported out later. This way, the producer can monitor the amounts of end products when they leave the plant (www.weighingsystems.com, 2018).

In cases where the ore entering the processing plant is owned by one company and is treated by another company, the most practical solution to measuring the mass of the ore treated is in-motion rail weighing or through conveyor belt weighers. This equipment is capable of reasonable accuracy if the best practices for selection, installation, and calibration as detailed in the AMIRA Code and the textbook (Morrison et al., 2008) are followed and providing the equipment is kept well-maintained and clean, which is often not the case (Gaylard et al., 2014).

Road trucks, rail wagons or ships are commonly used for the transportation of concentrates where the material could be transferred in tankers in a slurry form, as filter cake, or as dry powder, usually weighed several times during the transfer.

Fig. 2. Railroad track scales (Rice Lake Weighing Systems Ltd.)

Usually, the in-motion weighing of materials in road or rail trucks (Fig. 2) is used for large quantities of ore or bulk commodities. The accuracy of in-motion weighing for rail trucks depends on:

- The truck layout at both ends of the weighing section;
- The fastening of the rails on these approaches (concrete or ballast);
- Constant speed over the weighing section, at a speed within the capability of the system;
- Good maintenance of the track, bogeys, and trucks in order to reduce impact and vibrations such as flat spots on the wheel.

The authors (Gaylard et al., 2009) also suggest that the weighbridges or platform scales should be designed in accordance with the following principles if they are going to be used for primary metal accounting purposes:

- The design range must take account of the various loads being measured to ensure that the mass to be measured is as high a proportion of the maximum range as possible without overloading;
- Ingress of water should be eliminated or a facility for ongoing regular removal incorporated;
- The installation must be level and the construction of the weigh frame must be such that distortion be eliminated;
- The weight indicator or print-out must have sufficient graduations in order to show the measured weight with the significant figures that are required to meet the specified accuracy requirement for the operation;
- Maintenance and operating personnel should undergo training in the correct operation, maintenance, and calibration of these scales;
- The indicator and other measuring elements should be in a weather- and tamper-proof casing;
- The zero reading should be checked every shift; ideally, scales should be checked by the operating personnel on a daily basis using internal check weighs;
- Results of these checks and of the regular inspections should be logged and analysed in order to establish the measuring error and any trends or bias;
- The weighing platforms should be checked regularly and kept clean;
- Access to the weighbridges/scales should be restricted to authorised operating and maintenance personnel only;
- The truck being weighed should be clean before loading or after offloading and the correct tare must be used (allowing for the driver, fuel, and packing equipment, such as tarpaulin covers);
- Free movement of the platform should not be restricted in any way, e.g. by touching the external frame or by spillage jamming in the gaps between the weighing platform and the frame;
- Overloading must not occur and loads must not be dropped onto the platform as this may damage the load cell and/or distort the platform;
- To eliminate the possibility of fraud, good supervision is required to ensure that checks are in operation.

In Chapter 3, entitled "Mass measurement" (Morrison et al., 2008), the authors discuss the design and usage of hopper/bin scales which are also capable of good accuracy although they require a more elaborate installation for loading and offloading the materials for weighing. Three or four load cells will be usually spaced equidistantly around the circumference. Authors propose that a rigid framework of support and stabilisation of the bin or tank should be introduced, so that the load cells are not affected by factors such as agitation, material flow or wind.

Dynamic weighing

Belt scales

Belt scales (weighers) (Fig. 3) enable the continuous weighing of large quantities of solid materials travelling on conveyer belts without the disruption to the process that batch weighing can produce. However, static scales are in general more accurate and capable of greater "sensitivity" since a larger quantity of material is being weighed at one time. In addition, in practice, the accuracy of belt scales in operation is often considerably poorer than should be expected because of the poor choice, system design, installation or bad operation or calibration (Morrison et al., 2008).

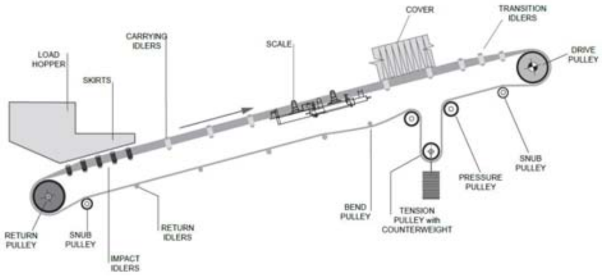
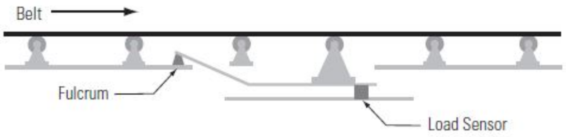
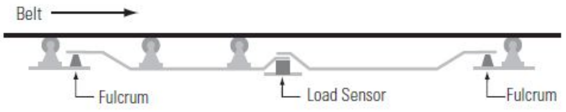


Fig. 3. Schematic diagram of belt conveyer system (Belt Scale Handbook 2016, Thayer Scale-Hyer Industries, Inc. Ltd.)

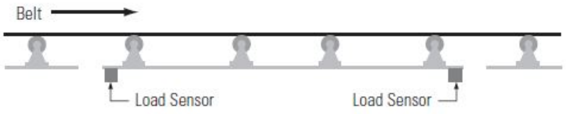
The weight on the conveyor belt is measured by sensing the force on one or more conveyor idlers. The motion of the material is measured by sensing the travel of the belt with a device which produces an "output" representing a fixed distance of belt travel. Because the measured force represents weight per unit of length (kg/m), it can be multiplied by the belt travel to acquire total weight. This function can be accomplished with an electro-mechanical or electronic integrator. With proper scaling, total weight may be accumulated in tons, long tons, or metric tons. In addition to displaying total weight passed over the belt conveyor scale, the most modern integrators also display instantaneous rate (i.e. kg/h or tons/h) and provide the transmitted output for remote monitoring and control requirements. The most viable belt conveyor scale systems operate in conformity with the above mentioned method of measuring weight per unit of length and multiplying that by the belt travel in order to determine the total material weight (Thermo Scientific Belt Conveyor Scale Handbook, 2012).



Single Pivot Carriage, Single Idler



Dual Pivot Carriage, Multiple Idler



Full-Floating Carriage, Multiple Idler

Fig. 4. Various common carriage designs of the conveyer belt measuring system (Thermo Scientific Belt Conveyor Scale Handbook, 2012)

Many manufacturers can be found in the field of mass measurement, and in particular in the conveyer belt weighing, but one of the world leaders and a most recognizable company in this area is Thermo Fisher Scientific Inc. Detailed and useful information has been presented in their Belt Conveyor Scale Handbook (2012). The following basic components and their function are quoted below:

- The scale carriage (Fig. 4) transmits the forces resulting from the belt load and directs those forces to the load sensor(s);
- The load sensor transduces the load force to a form acceptable to the mass totaliser;
- The belt travel (speed) pick-up contacts the belt and transmits belt travel (speed) to the speed sensor;
- The belt travel (speed) sensor transduces the belt travel (speed) to a form acceptable to the mass totaliser;
- The mass totaliser (integrator) computes the total mass that has passed over the belt conveyor scale and provides for the indication and recording of that value. Typically, the mass totaliser will also provide a mass flow rate indication.

The scale carriage must transmit the forces resulting from the material on the conveyor belt to the load sensor without adding any extraneous forces. It is important that no forces originating from belt travel or belt side travel be converted to a force on the load sensor. A draw of a single weigh idler showing forces in two dimensions is shown on Figure 5. Force F actually is sensed by the idler, but the scale carriage must transmit only force V to the load sensor. Force H must not be changed to a force acting on the load cell as a false representation of force V.

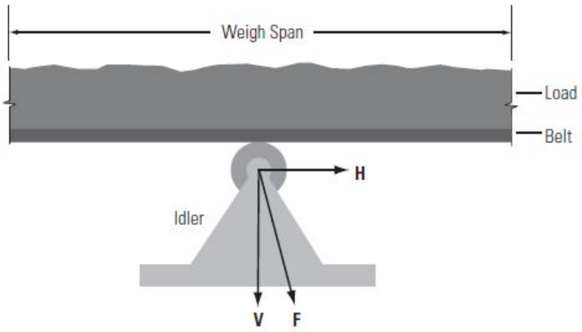


Fig. 5. Single weigh idler (Thermo Scientific Belt Conveyor Scale Handbook, 2012)

Morrison et al. (2008) suggest that the accuracy of conveyer belt (Fig. 6) weighing could be affected by the following:

- Flexibility of the weigh carriage;
- Spillage onto the weigh section;
- Belt effects such as tension, stiffness, and misalignment of the belt or idlers;
- Error in the belt speed measurement;
- Errors in the various processes of the measurement chain;
- Calibration errors and poor calibration techniques;
- Changes in the material being conveyed;
- Belt loading (proportion of design and variability);
- Poor operation, housekeeping, and maintenance;
- External environmental factors such as wind, dust, and excessive vibration or shocks;

Fig. 6. Four Idler Belt Weigher - Thermo Scientific Ramsey Series 14 (Ramsey Catalogue, Thermo Fisher Scientific Inc., 2018)

Morrison et al. (2008) explain that various methods could be applied for accurate measurement of the conveyor belt travel speed, which is as important as the mass on the conveyer because any error is directly proportional to the mass flow. The authors also suggest that, for authentic metal accounting, high quality equipment should be used and the belt speed measurement be derived from a cylinder or wheel (Fig. 7) in contact with the belt itself. This wheel should be: fitted so that it is in contact with the belt at all times (spring loaded); fitted at 90° to the direction of belt travel in the centre of the belt; of as large a diameter as is practical and as close to the weigher as possible. In general, the more idlers on a weigh frame, the less the effect of belt tension and alignment and the longer the instrument will remain in calibration (Amira, 2007).

Fig. 7. Tachometer for belt speed measurement (Spangenberg, 2012)

Various calibration methods exist such as: dead (static) test weights with the belt stopped or operating; use of an installed calibration test weight with the empty belt running; test chains or the material-run (bulk test) method. Calibration should cover a range of 20-100% of the belt loading for static tests. Testing over a range is not possible with an installed calibration weight, nor is it practical for material tests (Annon, 2003).

It has been suggested (Thermo Scientific Belt Conveyor Scale Handbook, 2012) that frequent zero calibrations may be impractical although it is recommended to do a daily zero calibration or zero balance. A change in zero balance can be expected over a long period of time due to material buildup on the carriage or to belt and idler wear. Zero calibration should only be performed by making a whole number of revolutions. The belt weight variance will be compensated for only if whole numbers of revolutions are used for zero calibration. Zero shifts in the order of 0.1 to 0.2% of full scale are normally the result of major weather changes, material buildup on the weighbridge, belt tracking, etc. Zero shifts of a larger magnitude normally are conveyor belt related and should be corrected prior to zero calibration. Most belt conveyor scale weighing errors result from improper zero calibration and lack of understanding of factors that cause zero calibration shifts or errors.

Morrison et al. (2008) propose that the static weights are the easiest and most convenient method but suffer from the following disadvantages: the dynamic effect of the normally loaded belt is excluded; the weight length must be accurately known and if the weigher is a pivoted type, the leverage ration must be accurately established.

The “material–run” method is preferred since it involves passing a known weight of the material (measured statistically in a weigh bin or a weigh bridge), which is normally measured by the weigher, over the specific weigher in the normal operating mode, thus incorporating the operating belt effects. This method is a requisite if the scale is to be certified but it necessitates facilities such as reference weigh bins or weighbridges to test weigh the material passing over the scale to a higher level of accuracy than that required for the belt scale being calibrated (Considine, 1993).

According to NIST 44 (Specifications, Tolerance, and Other Technical Requirements for Weighing and Measuring Devices, Handbook 44, 2015), some of the significant requirements for a material run test are presented below:

- The test shall be conducted at normal operating load;
- The test shall be conducted over a period of:
    - not less than 1000 scale divisions;
    - at least three complete revolutions of the belt;
    - at least 10 minutes of operation.
- A zero load test shall be conducted prior to the material test for at least three complete revolutions and ten minutes and immediately after the material test. The zero error for the former shall not exceed ± 0.06% or ±1 scale division after the zero adjustment, and for the latter test it shall not exceed ± 0.12% or ±2 divisions, whichever is less;
- The check weight scale must be capable of an accuracy of at least ±0.1%;
- After a zero load test, the totaliser must not change more than 3 scale divisions for one complete belt revolution;
- If the error shown by the material test is less than 0.25%, no adjustments should be made. If it is grater than 0.25% but less than 0.75%, adjustment may be made after notifying the statutory authority. If it is over 0.75%, adjustment may only be made by a

competent person after notifying the authority and if the error is over 0.75% an official test is required.

Nuclear Belt Weighers

Nuclear belt weighers use the principle of the adsorption of nuclear (gamma) radiation to measure belt loading. Suppliers provide guides to help select electro-mechanical or nuclear weighers for a specific application (Morrison et al, 2008). Such a belt weigher is shown on figure 8, where a fan-shaped collimated beam of radiation is transmitted from the source through the process material and the conveyor to the detector.

The nuclear belt weighers are simple to install and are less affected by belt tension or misalignment, so the conveyer design is not as important. Besides, they are not susceptible to external forces such as wind, they are less maintenance intensive, and easier to calibrate. However, they have the some operational limitations as to the measurement of belt speed, plant housekeeping moisture determination and regular calibration as any type of belt weigher. Most importantly, they are affected by variation in the size, composition, and shape of the material being measured and are therefore normally less accurate than electro-echanical weighers, with maximum errors of ±1 to ±2% of full scale being achievable but higher levels being normal (Jost, 1986).

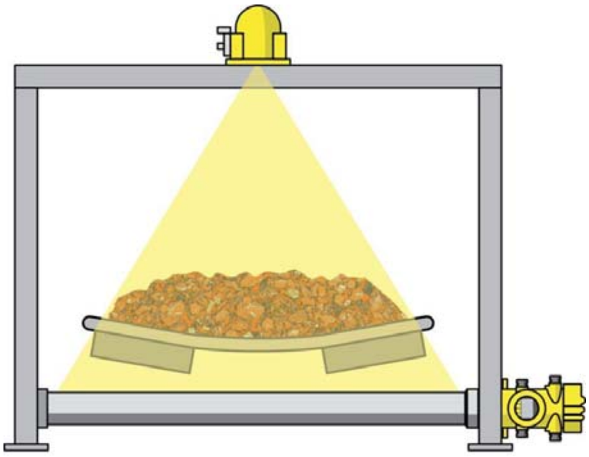


Fig. 8. Nuclear Belt Scale (Measuring Bulk Solids on a Conveyor, http://www.powderbulksolids.com, 2018)

The relevant national nuclear authorities control their use and maintenance. In certain applications, they can also be used, with neutron or microwave gauges to determine moisture content. They should not be used for metal accounting measurements.

Conclusion

As was mentioned in the Introduction and thanks to researchers such as Rob Morrison, Peter Gaylard, Ralph Holmes, Neville Randolph, Mike Wortley, Richard Beck etc., who were included in AMIRA P754 project, 'Metal Accounting and Reconciliation' and developed the Code of Practice for Metal Accounting for the Mining and Metallurgical Industry, the primary objective of mass measurement for metal accounting has been determined. It is to provide a result for the mass or mass flow of the component of interest that is free of bias, or at least such bias that can be established, and with a random error that is within the maximum limits required for the metal accounting system.

This review was made possible by the research carried out by the AMIRA International P754 Program and by the above mentioned scientists whose efforts and knowledge have contributed to the publication of various textbooks, research papers, and industrial reports. More details on this topic can be found in the literature sources listed below.

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