Mass measurement for metal accounting—principles, practice, and pitfalls

C.M.G. WORTLEY
Consulting Engineer

One of the major deliverables of the AMIRA P754 Project, which was sponsored by several major mining companies, was a code of practice and guidelines for metal accounting for the mining and metallurgical industry. These had the objective of improving the auditability and transparency of metal accounting from mine to product, thus assisting in good corporate governance.

The overriding objective 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, to a defined accuracy suitable for metal balancing. As such, it is the first measurement in the chain that includes sampling, sample preparation and analysis, each of which introduces its own errors. Materials often contain moisture, the proportion of which must also be established in order to obtain the dry mass. They may also have to be measured as a volume or mass/mass flow of slurry, or in stockpiles or storage areas, in which case the relative density must be measured. Both the density and moisture measurement often introduce significant error.

Whereas a great deal of effort has been directed at sampling, sample preparation and analysis to improve accuracy and establish the error, the same can seldom be said for the mass determination, including the moisture and density measurements. The possible major causes of error are highlighted and methods of reducing them discussed.

Mass measurement can be classified into those measurements necessary for custody transfer and primary accounting of the input and output streams to a plant or operation, and measurements required for secondary accounting, or management control. The latter include intra company transfers and plant area performance, and those required for plant control only. This paper is concerned only with primary accounting measurements. The code and best practice state that the equipment should be certified (assized) as is required for custody transfer.

The most accurate and precise of the various possible methods is the static measurement of mass on a weighbridge, platform scale or a weigh bin. If static measurement is not possible, which is often the case for ore fed to a plant, possible alternatives are electromechanical conveyor belt weighers or in-motion weighing of rail trucks. In all cases the material must be adequately sampled to enable a representative moisture content to be determined to calculate the dry mass. Where material is flowing inside conduits, only certain types of the multiplicity of flow meters available may be used and, in the case of slurries, very few flow meters are suitable. As most flow meters measure volume or velocity, the density of the material must also be measured.

The basic requirements in order to achieve satisfactory results for the mass, of the component of interest, are listed, as well as common problems and pitfalls encountered in practice.

The measurement of the mass of stockpiles and in-plant stocks, often required for metal accounting, is often the largest source of error in metal balances. The reasons for this and methods for reducing and managing the effect are discussed.
details on the Code are given in an earlier paper3.

Since the publication of the Code, several audits to test conformance have been conducted on various operations by the author, covering mass measurement aspects. Some of the lessons and learning points from these are incorporated in this paper.

Introduction

The overriding objective of mass measurement for metal accounting purposes 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, to a defined accuracy suitable for metal balancing. Materials often contain moisture, the proportion of which must also be established in order to obtain the dry mass. They may also have to be measured as a volume or mass/mass flow of slurry in tanks or conduits, or in stockpiles or storage areas, in which case the relative density must be measured. Both the density and moisture measurement often introduce significant errors in the calculation of the mass of dry solids.

Primary accounting is defined as accounting for the metal balance across an entire plant. Thus the plant is treated as a black box with primary accounting applying to only the entry and exit streams. These streams, being the most critical, have the most stringent requirements such as certified (assized) weighing equipment, if possible, and the ability to establish the distribution of the random errors associated with the measurements. The mass measurement of these streams is the subject of this paper.

The essentials for any mass measurement system to achieve reliable results for primary metal accounting and to adhere to the principles of the code are:

• 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 recognized 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, to facilitate error detection and statistical analysis 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, 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.

Methods of measuring mass

Mass measurement equipment is divided into three main categories:

• Static, where the load is stationary
• Dynamic, where the mass is in continuous motion
• Hybrid, where the mass is weighed statically and the material flows through in batches

The various methods for measuring mass/volume are static platform scales and weighbridges, hybrid weigh hoppers/bins and gantry scales, in-motion railroad weighing, conveyor belt weighing and volume or mass flow meters. Survey techniques are used to measure the volume of stock piles or material in bins, and for bulk commodity shipments, draught surveys are sometimes used.

Only the equipment in most common use, and usually used for metal accounting in the metallurgical industry, will be discussed in this paper. These are platform scales and weighbridges, electromechanical conveyor belt weighers, in-motion rail weighers and electromagnetic flow meters, usually in conjunction with density meters.

Any methods utilizing a volume (e.g. survey) or volume flow determination (e.g. magnetic flow meter) require the measurement of bulk density or the specific gravity of the material and calculation of the solids mass.

Numerous international and national standards as well as government metrological acts and regulations exist, which must be followed for custody transfer applications and if certification is to be granted. There is an extensive list of these in the Code and in the textbook; however, a few important ones are listed in the references in this paper.

Accuracy and precision of mass measurement

A mass measurement for metal accounting should be as close to the ‘true’ value as possible (accurate) and also be reproducible (precise). The objective of mass measurement for metal accounting is to reduce random errors to within acceptable limits and to eliminate bias (systematic errors). Unfortunately in the case of mass measurement, especially belt weighers, the errors are often systematic resulting in biased values being reported.

Errors are possible throughout the mass measuring chain, including those introduced by the equipment layout, the material being measured and mechanical, physical or environmental aspects, by the measuring source such as a load cell, or by the various processes in the electronic circuits, leading to a cumulative overall system error. The more steps in the chain, the greater the possibility of error and the greater the magnitude, as all errors are cumulative. The various possible sources of errors for each method and system are covered in detail in the textbook.

In the case of static mass measurement, the ‘true’ value is established by calibration and certification utilizing test weights (which have been certified for use in custody transfer applications and are traceable back to national and international standards) and the equipment is adjusted so that it records this value. In the case of mass flow measurement by conveyor belt weigher or electromagnetic flow meter, the calibration is more complex, but should involve passing a known weight of the actual material being measured, the weight of which has been established on certified equipment, over or through the equipment and adjusting the reading to this ‘true’ value, if it is outside predetermined limits.

Assuming that best practice has been followed in all the aspects described in the AMIRA Code and Guidelines, and that the applicable national or international standard for that particular type of equipment has been utilized, indicative precisions (quoted as a coefficient of variation at full scale) that can be obtained for platform scales are ±0.05% to ±0.2%, for weighbridges ±0.1% to ±0.2%, weigh bins ±0.1% to ±0.25%, and gantry scales ±0.15% to ±0.4%. If the mass has to be measured whilst in motion then the accuracy attainable is generally worse, especially in practice. Nevertheless precisions of ±0.5% are achievable for in motion weighing and electromechanical belt weighers. For electromagnetic flow meters ±0.5% on clean water or liquids is possible, but accuracy is much worse on slurries.
It is obvious that static mass measurement should be the first choice wherever possible as the precision and accuracy are better because there are no dynamic effects and calibration is relatively simple. If the use of static mass measurement is not possible or practical then either in-motion weighing or electromagnetic belt weighers should be used. Electromagnetic flow meters should be used only as a last resort and are not suitable for primary accounting on slurries.

**Static mass measurement**

**Platform scales and weighbridges**

This is the most common form of mass measurement equipment. The load is usually sensed by one or more load cells directly under the weighing platform, or in some older scales, by a system of levers or counterbalances from the platform or weighbridge. These scales should be certified for use in primary accounting. The requirements for the design, installation, operation, certification and calibration are covered in the textbook and laid down by international and national standards such as OIML R51, OIML R76, SABS 1649 and the Trade Metrology Act and Regulations 7.

For custody transfer and certification the equipment must be calibrated, by an approved outside body, with certified weights traceable back through national standards to the International Unit of Mass held in France. Regular calibrations should also be carried out and all values recorded and trended to establish error limits and recognize bias.

**Hopper/bin and gantry scales**

Hopper/bin scales are also capable of good accuracy, although they require a more elaborate installation for loading or offloading of the materials for weighing. They will usually utilize three or four load cells spaced equidistantly around the periphery of the bin. These scales should be calibrated with certified test weights and certified by the relevant authorities for metal accounting in the same manner as for platform scales. Other regular checks should also be carried out as for platform scales and all the values recorded and analysed to establish the error. Accuracy requires a rigid framework of support and stabilization of the bin or tank so that the load cells are not affected by factors such as agitation, material flow or wind. They should also have a facility for calibration for ease of loading of the test weight.

**Measurement of mass in motion**

**In motion weighing**

This is usually utilized for large quantities such as ore or bulk commodities transported either by road truck or in rail cars. However, in-motion weighing is not acceptable for primary accounting or certification for road trucks due to acceleration and deceleration effects. The accuracy of in-motion weighing for rail trucks is dependent on correct track layout, installation and good maintenance of the track and rolling stock. Speed over the weighing section must be constant. Each truck should be weighed empty and full on the same weigher and the tare established on every occasion.

Modern in-motion weighers normally weigh the individual axles of the rail truck bogeys without the necessity of uncoupling, utilizing multiple pairs of strain gauges installed in or attached to the rail web, and software which can compensate for coupling effects and speed errors. Train speeds of up to 20 km per hour are now permissible and the weighers can be certified.

**Rail in-motion weighers**

Rail in-motion weighers can be calibrated and certified according to standards such as OIML R106 and R134 and National Trade and Metrology Regulations. The calibration requires the use of preweighed, certified test hoppers or wagons at both normal full and tare weights, passing over the weigh section for a specified number of times in both directions. Certification is usually required annually, but weighers should be checked internally on a more frequent basis. As for all mass measurement these measurements should be recorded and analysed to determine the operating error.

**Electromechanical belt weighers**

In practice, in the mining/metallurgical industry, the main primary accounting input stream to the treatment plant is run of mine ore from the mining operation, the mass of which is measured on conveyor belts by belt weighers. Although this is a difficult product to measure because of the variation in size, moisture content and flow rate, it is possible with good design and practice to obtain reasonable accuracy. However, in many cases, although the measurement will be more accurate than the use of truck or hopper factors, it is compromised by poor design and the reluctance to spend the necessary money to improve the installations, or poor operating and calibration procedures.

As this method is common, suffers from a numerous problems in operation and is usually the tonnage measurement for the mine/plant interface, it will be addressed in slightly more detail in this paper than the others. However, it is covered much more fully in the textbook, chapter 3.

Only electromechanical belt weighers should be used for primary accounting. Nuclear weighers are not suitable as the values are affected by changes in the material being conveyed.

The basic components of an electromechanical belt scale are:

- The scale suspension (weighing) section on the conveyor, which transmits the load on the belt to the load cells (sensors)
- The load sensor(s), which converts the load force to a form acceptable to the mass totaliser
- The belt travel speed pickup, which contacts the belt and transmits the belt speed to the speed sensor
- The belt travel speed sensor, which converts the belt speed to a form suitable to the mass totalizer
- The mass totalizer, which computes the mass travel over the conveyor scales by integrating the mass measured and the speed and indicates and records that value.

**Design and operation—bell weighers**

The scale suspension must be rigid with torsional stability, designed with minimal flat surfaces to reduce spillage build-up and capable of withstanding high temporary overloads. The suspension may have a single weigh idler or multiple weigh idlers (normally up to 6 or 8) and be of various designs such as pivoting, floating and counterweight. They may be fitted with a single load cell or multiple load cells. Some belt weighers are fitted with counterweights and levers to counteract the weight of the empty belt and the weigh carriage and thus increase...
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 (NIST 44). This is obviously not possible utilizing the installed weight calibration.

Static weights are the easiest and most convenient method, but suffer from the disadvantages that the dynamic effects of the normally loaded belt are excluded, that the weight length must be accurately known and that, if the weigher is a pivoted type, the leverage ratio must be accurately established.

The material-run is the preferred method (and is required for certification) as it involves passing a known weight of the material normally measured by the weigher (measured statically in a weigh bin or over a weigh bridge), over the specific weigher in the normal operating mode and thus incorporates the operating belt effects. This method necessitates facilities such as reference weigh bins or weighbridges to test weigh the material passing over the scale. Certification has to be performed by an accredited company.

Test roller chains, of certified weight in Kg/m, are the next most suitable method as the conveyor and weigher system are operating at the usual load.

To maintain accuracy the following checks and calibrations should be carried out:

- Frequent visual checks of cleanliness, belt and idler condition and alignment
- Belt speed at zero and operating conditions and span mass checks should be performed frequently (weekly or bi-weekly) as well as a check with static weights, or the installed test weight if fitted, or preferably with installed dedicated test chains. Zero mass checks should be performed more frequently, daily if possible. These readings can be checked using the integrator readings or microprocessor, over the prescribed time period. However, the belt speed should also be checked manually using a hand held tachometer and checking the distance travelled and time, by marking the belt. All of these checks should be carried out over an integral number of at least three belt revolutions and for not less than ten minutes with the conveyor running at the beginning and end of the test. These tests can be performed inhouse or by outside independent companies
- Checks can also include belt cuts (stopped belt sampling) of material from the belt to establish the belt moisture (these samples are often required to check the moisture of the material on the belt)
- Periodically (every three months) the weigher should be checked and calibrated by an outside independent company. These checks should include the idler vertical and horizontal alignment
- The frequency of material-run calibration is dependent on operating experience on the specific installation (periods of 3–6 months are common)
- Test chains or test weights should be kept clean, free of corrosion and the weights should be checked and recertified periodically.

Sources of error

The sources of error for the wet mass measured by a belt weigher, range from those due to the conveyor belt and installation to those arising from the electronics. Some of the common sources of error are listed below:

- Belt tension, stiffness and misalignment, and the effects
calibrate the associated density meter at the same time as components must be known and measured. The former is wear of the conduit.
surges, flow disturbances such as bends, tees or other unsteady flow conditions such as entrained air and pump measurement for the meter must be specified and accounted, since the properties of the fluid/slurry being flotation feed, where the measurement is used for primary critical attention is not paid to the density measurement, there is no point in measuring the volume flow to ±0.5%, if over or under loading, or cyclic load variations and misleading. For custody transfer the uncertainty of flow measurement for the meter must be specified and weight is high. An error in the moisture value of say 1% absolute means the dry mass will also be 1% high or low. The measurement of moisture may be:

- Measurement of moisture in the material in road/rail trucks, tankers or other containers
- Measurement of the moisture content in material on a conveyor belt
- Measurement of moisture content of material in bins/hoppers or stockpiles.

It is important to ensure that samples for moisture determination are taken in such a manner to ensure that the moisture in the sample is representative of the material being weighed and that no evaporation or water ingress occurs, before the determination takes place. It is also very important to ensure that any analysis is carried out on the sample that has been used for moisture determination, or an appropriate correction made, in order that the analytical result can be related directly to the dry tonnes value. The most suitable way to measure moisture is by bulk or laboratory tests, where a known weight of a representative sample is dried, so as to drive off free water only and the mass measured can have a significant effect on the reading. For convenience and practical reasons, mass flow in closed conduits is often determined by measuring volume flow rate plus density or specific gravity in order to calculate the dry mass. This type of measurement is very common in the extractive industries for process flows and liquid and/or gaseous effluents. The degree of uncertainty in the mass flow is then made up of that resulting from the volumetric measurement as well as errors in the density determination. There are over a hundred types of flow meters commercially available, operating on ten different principles. However, in the metallurgical industry, many of the key process flows, in conduits, required for metal accounting, are abrasive slurries in relatively large quantities containing a significant amount of solids. This effectively limits the choice of a suitable meter for these applications to an electromagnetic flow meter, providing the fluid is conductive, and this is the only method addressed in this paper. As their use is relatively limited and the subject has been fully addressed in the textbook, chapter 3, only a few critical points are addressed here.

Often claims of accuracy for flow meters are ambiguous and misleading. For custody transfer the uncertainty of flow measurement for the meter must be specified and specifications must conform to international standards. The initial calibration and certification must also be conducted in terms of the applicable ISO standards. Other standards cover the manufacture, design and installation.

For critical metal accounting flows, such as thicker or flotation feed, where the measurement is used for primary accounting, since the properties of the fluid/slurry being measured can have a significant effect on the reading. Errors in the integration, electronics and read out. The uncertainty in the density measurement has a direct
effect on the resultant calculated dry mass and can be large, as for example in the case of low SG slurries. At an SG of 1.25, a 2% error in the density measurement translates into a 10% mass flow error, assuming that the carrying fluid has an SG of 1.00. In operating plants it is important to note that this fluid is often recirculated water, which may have a varying SG and which may be greater than 1.00, due to the build up of salts. If the SG of the water is 1.05, then the error in the above example will increase to 12.5%. Thus there is no point in measuring the volume flow to ±0.5%, if critical attention is not paid to the density measurement, including both the solid and solution components of the slurry.

For bins and silos, ultrasonic level detectors are used and
this level used to calculate a mass based on the volume of material in the bin. The volume has to be determined by survey and geometry and used to calibrate the level reading. This volume should take account of the dead load in the bin.

To relate the tonnage of broken ore measured at the treatment plant to that mined, requires the knowledge of the density of the broken rock, as the tonnage has to be back-calculated to the volume of rock mined, as determined by survey.

The most precise and preferred method for measuring relative or bulk density, is by bulk, laboratory or plant tests whereby an accurately known volume is weighed and the bulk/solid/liquid/slurry density calculated. The volume of solids can be determined by various methods, including displacement of liquid. The precision of the measurement derived from small specific gravity flasks is usually poor and is not adequate for the calibration of density meters. This calibration should be carried out by the accurate weighing of larger quantities of known volume in containers such as 200 litre drums or, preferably, the use of a weigh tank on load cells.

Nuclear (gamma) meters are often used for density measurement of slurry flow in conduits, in conjunction with an electromagnetic flow meter. The correct choice and accuracy is installation specific and the guidelines supplied by the vendors must be adhered to.

The essentials to achieve good results with density meters and the factors that effect accuracy are very similar to those for the electromagnetic flow meters. The meters themselves are capable of ±0.5% accuracy, but this is often not obtained in plant conditions, because of poor installation, inhomogeneity and particle size changes of the solids in the slurry.

As the mineral contents of the slurry can affect the measurement, ideally the calibration should be performed in the field at two points on the scale by measuring the weights of known volumes of water and slurry passed through the meter. It is logical to combine this check with the calibration of the flow meter. In practice, this is seldom done as the installation and design does not facilitate this operation and it is relatively time consuming. Usually calibration is performed using water as 1.00 density as the zero and metal plates of a known absorption to establish the range. As modern density meters are supplied with microprocessors that permit remote electronic calibration, sometimes this is the only method used. The relative densities of the solids, the carrier solution and the slurry must be checked regularly.

Measurement of stocks and stockpiles
Mass in storage areas such as stocks and stockpiles is often a significant quantity and is material to metal accounting. It is usually difficult to determine to a level of accuracy sufficient for accounting purposes and is subject to a high level of uncertainty. It can conceal mass measurement and accounting discrepancies if measured only by difference or survey and not cross checked by other means. It is far better to sample and weigh the input and output, which can usually be performed to a higher level of accuracy than measuring the stock, calculate the stockpile by difference, run stocks to zero regularly and make the necessary corrections. The recommended practice for stockpile assessment is to have a system of dual parallel piles, which must be emptied in turn at regular intervals.

Errors in the mass and content of stocks are often a major source of error in the metallurgical balance and it is essential that stock takes are conducted at regular intervals.

It is possible to measure the volume of a stockpile to an accuracy of better than ±5%. However, there are no international standards and this accuracy is dependent on the number of survey points taken and the skill of the surveyor. The obtaining of a representative sample to measure the bulk density and moisture of the material in the stockpile, to determine the dry solid mass, is much more difficult. The bulk density of many materials is changed by compaction, ageing, swelling or oxidation and is also affected by stockpile practice, such as trucks driving over the pile, and the method of dumping. If the material is not homogenous in size and content, which is the usual case, sampling of a stockpile to the accuracy desirable for metal accounting, is impossible. The uncertainty of the metal content could be as poor as ±15%.

It is true to say that the only time when a stockpile value is correct is when it is zero.

Measurement of process inventory
As is the case for plant stocks and stockpiles, the error in the mass determination of process inventory is often one of the greatest sources of error in a metallurgical balance. It is essential to conduct regular stock takes to recognized procedures and, in cases where the value is material, empty the process in stages.

Unless tanks or bins are on load cells, the calculation of the mass will involve a volume and bulk density measurement with exactly the same caveats as for stockpiles.

Problems and pitfalls
Problems in obtaining mass measurements of sufficient accuracy for metal accounting may be divided into four areas. These are design and equipment selection, certification and calibration, record keeping and good housekeeping and management.

Inadequacies in the first area are often inherited and require modifications, which may be relatively costly. However, the other three areas are directly controllable by plant management and some only require good housekeeping practice. General problems observed that apply to all the methods of mass measurement, even on suitable equipment and systems, are:

• Poor housekeeping and cleanliness with spillage compromising the weighing system and causing errors
• Poor and nonstandard calibration techniques
• Insufficient and inadequate regular checks
• Use of dirty or corroded test weights
• Inadequate or nonexistent records of checks and calibrations including the as-found and corrected values. Thus no history is available nor records of errors corrected
• No trending or analysis of the calibration results to check for bias and to establish confidence levels.

Static mass measurement
The design, selection and installation of platform scales and weighbridges is usually adequate, although in some installations observed, it would be desirable for additional automation of the weighing system and automatic recording of results in order to remove the possibility of operator and transcription errors.
In practice on operating plants, platform scales and weighbridges are usually certified by outside officially recognized bodies using traceable certified weights at annual or biannual intervals. However, in the audits conducted by the author, the checks conducted internally between these external audits are not conducted in terms of standard procedures and utilize weights which have not been checked for many years. Weigh hoppers, bin or tanks are seldom calibrated using test weights and in many cases regular calibration is impossible as there are no facilities to hang the test weights, which may total several tons. If the measured material is slurry in a tank, the calculation of the dry mass is suspect, as the relative density of the components is seldom checked and the volume measured inaccurate.

The other problems observed include housekeeping issues such as spillage of material onto the weigh platform or weigh frame or jamming the free movement of the platform, use of the incorrect tare, lack of an adequate moisture sample for the material being weighed, and inadequate record keeping. These often compromise the results from a basically sound installation.

### In-motion weighing

These systems have often been retrofitted into existing rail systems, thus sometimes the installations are not ideal. In addition, in-motion weighing has developed rapidly and performance has been improved over the past several years. In practical applications observed, the major problems stem from poor track and rolling stock condition, operating practices and inadequate calibration techniques. In the case of the latter, it is necessary to utilize empty and full test rail trucks of known (certified) weight in order to perform multiple calibrations over the measurement range. Such trucks are nominally available from Transnet. Alternatively, in-house trucks can be set up. Lightning damage or theft/vandalism can also be a problem, but protection can be incorporated into the design.

### Conveyor belt weighers

The most common problem observed was in the design, layout and location of the conveyor belt weighers used to measure the ore delivered to the plant. Invariably the belt weighers, which in themselves may be capable of an accuracy suitable for metal accounting, are located on a long steeply inclined conveyor belt often with intermittent and highly variable feed and moisture content. It is not uncommon to see weighers operating with free water running down the belt, or where the belt is torn allowing spillage onto the weigh carriage or where some of the weigh idlers are jammed. In addition, there are no facilities (such as weigh bins or diversion chutes) to conduct dynamic material run calibrations or even dynamic chain calibration, as required. The same applies to a lesser extent to the measurement of the ore feed to the mills; although if there are crushing stages, the ore mass flow and size distribution is more uniform and thus more suitable for accurate mass measurement. It is apparent that very little thought went into the design of the mass measurement during the initial plant construction and belt weighers often appear to be added as an afterthought. While this may be understandable in older plants, the same has been observed in plants built in the last few years. Considering that these measurements provide the metal accounting mass input, sometimes from multiple sources including toll material, it is most disappointing that only in a few cases was the primary accounting mass measurement system adequate and that some of these were then compromised by poor calibration procedures or maintenance.

In the audits conducted to date, no applications have yet been observed where the belt weighers have been certified (although this is practised in the coal and iron ore industries) and very few material run (bulk) tests are carried out. This is hardly surprising because, if the design does not facilitate such tests is time consuming and requires very careful supervision to obtain any meaningful results. Calibration techniques for belt weighers that have been observed are highly variable and unfortunately their results and use for determining the accuracy of metal accounting mass measurements are often compromised by some or all of the following factors:

- Correcting on every occasion for as-found errors with or without recording these, even if these are random and within the accuracy of the system
- Calibrating at an insufficient frequency or with incorrect or nonstandard procedures or for an insufficient operating duration
- Not checking the belt speed adequately
- Calibrating with spillage on the weighbridge or platform or with water on the belt
- Poor belt condition or belt tracking
- Jammed, eccentric or misaligned weigh idlers
- Utilizing dirty, corroded, or unchecked and uncertified test weights
- Utilizing static calibrations only
- Utilizing electronic calibrations only

With the electronic integrators now used with belt weighers, calibration utilizing the software supplied, accomplished by simply pressing a series of buttons, and resetting the belt speed reading and zero and span mass measurements automatically, is sometimes the only method used, in some cases with little understanding of the fundamentals. There is often no record of these corrections and the identification of bias is not possible. There is no substitute for fundamental checks of belt speed by timing a measured distance of travel and of belt loadings by calibration with known masses.

### Electromagnetic flow meters

In the plants audited these were seldom used for primary accounting, although they were used for internal custody transfer between plant sections. In general, the results obtained are suspect and inaccurate. In some cases, basic installation requirements were not adhered to and in none of the observed applications were there facilities (such as weigh tanks) to calibrate the meters utilizing the material being measured. The meters are often calibrated only on plant water, thus the values obtained could be 10–20% in error. In some cases all calibrations and checks were conducted in-house and outside independent organizations were not utilized periodically, as required by the code and best practice.

### Moisture measurement

Meaningful moisture measurements are seldom taken, as the moisture samples are often taken at a point separate from the location of the mass measurement, and are not representative of the material, especially on a conveyor belt or from a bin or stockpile. In some cases ‘historical’ values are assumed. This can easily introduce errors of 1–2% in the dry mass, even for relatively dry material on conveyor belts and much higher values in the case of stockpiles.

### Density measurement

Experience from plant audits shows the density used to calculate the solids mass to be a significant source of error for many of the same reasons applicable to magnetic flow meters. Thus there are no facilities such as weigh tanks to
calibrate density meters on the actual material, and plant water and metal plates only are used. Bulk densities of stockpiles are assumed, and constant, independent of the particle size, degree of compression or age of the material. Densities of the solid and liquid components of a slurry for mass in a tank or flowing in a conduit are assumed (with that of the water, which is usually recycled process water, assumed as 1.00) or the material has changed from that for which the meter was designed.

Measurement of stocks
As stated before, the mass measurement of stockpiles, bins, etc. are impossible with any level of accuracy, because of the variations in moisture content and bulk density. It is common practice to assume the latter two figures, often based on some long standing values, the sources of which are often not available. Although surveyed regularly to establish the volume, in many cases stockpiles were haphazardly managed and very seldom run to zero.

Conclusions
The purpose of mass measurement for metal accounting is to provide a value for the dry mass of the component of interest to use in the metal balance and for calculation of the monetary value for use in the financial statements. Therefore, the value should be substantially free of bias, or at least such that the bias can be determined, and with a random error that is within the error limits required for the metal accounting system. As well as the measurement of the mass, this requires the measurement of the moisture and in cases where volume is the only measurement possible, of the relative or bulk densities. The errors from these measurements are accumulative in the dry solid mass calculated.

The mass measurement equipment for custody transfer is required to be certified (often by law or contract). As primary accounting measurements are custody transfers in most cases, certification is also recommended and is required by the Code.

The most applicable methods of mass measurement to use for primary accounting have been discussed, indicating some of the basic requirements in selection and design, operation and maintenance, calibration and certification and record keeping; in order to optimize the performance and obtain results within margins of error suitable for metal accounting.

The problems with measurement of stocks have been highlighted and the necessity to manage and minimize these stressed.

The major problems and pitfalls, which may lead to erroneous values and cause bias, which may not be detected, that have been observed in various operating plants, have been listed. From these observations, it is the author’s opinion that mass measurement has often been treated as the poor relation in plant design and the measurement points added as an afterthought, instead of building in the requirements at the beginning, thus resulting in unsuitable equipment or installation.

It is even more disappointing to see suitable equipment and installations being compromised by poor operating, maintenance and calibration procedures.

It is believed that following the principles outlined in this paper, the Code of Practice and textbook will result in cost-effective installations and measurements, which will improve the margins of error on the measurement of mass.

Acknowledgements
I would like to acknowledge the agreement of AMIRA International and the sponsors of the AMIRA P754 Project to the publication of this paper and the assistance of my colleagues P.G. Gaylard, N.G. Randolph, R.D. Morrison and R.D. Beck as part of the P754 team.

References
6. SABS 1649: Non-automatic self-indicating and semi-self-indicating weighing instruments. (Annexure B gives the requirements for verification and shows maximum tolerances that are permissible for new installations as well as instruments in service), 1995.
7. Trade and Metrology Act 1973 and Regulations

---

Christopher Michael George Wortley (Mike)
Consultant

Mike joined Union Corporation upon graduation. After an initial spell on various gold mines of the group he was transferred to Impala Platinum where he worked for twenty five years on the various metallurgical operations of the Company in Springs, Rustenburg and the Head office in Johannesburg, latterly as Director Operations. Mike then transferred to Gencor/Billiton as Technical Manager Business Development, seeking new business opportunities for the company, mainly in base metals. After retiring from Billiton, Mike spent a few years at Hatch Africa as Senior Consultant and Regional Director Technologies.