

Paul Reagan, Sampling Associates International, US, and Jim Freeman, Kanawha Scales & Systems, US, review the basic principles of weighing technologies available, highlighting the strengths and weaknesses of each method.

For commercial transactions of bulk commodities, determination of the quantity of material is critical. Weight discrepancies are often the source of vigorous commercial disputes. This article surveys the important issues in the weighing of bulk materials and the different weighing technologies available. While draft surveys are a widely used method for weight determination for waterborne shipments of bulk commodities, this technique is not addressed here, as it is not strictly a weighing technology.

#### **Important** issues

There are a number of significant issues to understand prior to any discussion of available technologies.

## Custody transfer vs process control

One very important issue is that there are two different general applications for most weighing technologies. The first application is for custody transfer, i.e. the official weight on which payment is made on the commercial transaction between a buyer and seller. The second is for process control, which means that it is only used for non-commercial purposes such as loading control, batching, blending and general inventory, but may not have or need the accuracy necessary for payment purposes. A frequent problem in the bulk materials industry is that equipment intended for process control is used for custody transfer purposes.

#### Maintenance and housekeeping

As with all sophisticated equipment, good preventive maintenance is important for performance. As the 'output' of scales is the weight of material, lack of maintenance leads to erroneous readings.

Good weighing practice requires special emphasis on housekeeping. One of the most frequent causes of poor scale performance is the buildup of loose material on or under the scale platform or weighbridge. This can add to the weight sensed by the weighing elements, especially if the scale is not tared or zeroed out prior to weighing. It can also cause errors by inhibiting proper scale movement. If not cleaned regularly, such buildup will further degrade scale performance through excessive part wear, corrosion and improper resistance to moving parts.

#### A certifiable scale still needs to be certified

'Certifiable' refers to the hardware, i.e. the fact that the scale is designed



Figure 1. Digital weight indicator.



Figure 2. Load cell assembly for weigh bin system. (Photo courtesy of Kanawha Scales & Systems.)

Table 1. The impact of different levels of weighing errors	
Weighing error percentage (±)	Cost of weighing error (US\$/year)
0.10	150,000
0.25	375,000
0.50	750,000
0.75	1.25 million
1.00	1.5 million



Figure 4. Certified calibration weights being loaded into certified weight cart. (Photo courtesy of Kanawha Scales & Systems.)



Figure 5. Continuous length single draft rail scale. (Photo courtesy of Rice Lake Weighing Systems.)

and manufactured to achieve the necessary accuracy for commercial transactions. 'Certified' means that, not only does the hardware have the necessary capability, but it is also installed, maintained, calibrated and tested to meet the required tolerances.

The use of equipment that is certifiable, but not certified, commonly results in scale systems that are assumed to be weighing accurately, but may in actuality perform quite poorly.

## Calibration and testing

There are a number of processes involved in the quality assurance of scale systems. Calibration is the process by which a scale is checked and brought into acceptable weighing accuracy tolerance limits by using specially manufactured weights of a known mass (calibra-

tion weights). All scales need to be calibrated and all need calibration weights, or valid weight substitution, to do so.

Some applications have calibration weights included, or built into the installation, whereas others need to have special calibration weights transported to the site each time calibration is performed.

Calibration is not the same as certification. Certification is a documented process where a scale is proven to perform to certain specifications and tolerances according to the governing authority for the jurisdiction in which the scale is physically located. It is also usually performed in the presence of a representative from the authority, and is required for custody transfer scales on which payment is made.

Calibration is an important prerequisite for the certification test but needs to be performed much more frequently, to ensure that scales continue to perform satisfactorily between official certifications. For example, many governing authorities require a certification test on an annual or semi-annual basis, while calibration is often performed weekly. Also, although process control scales that are not used for payment

do not need to be certified, they still need to be calibrated regularly.

#### The cost of errors

Weighing errors are common. Simply stated, the higher the weighing error, the higher the arror in payment that one party transfers to another. It is not uncommon to find systems, in a custody transfer application, with errors of  $\pm 0.75\%$  or worse. Table 1 shows the impact of different levels of weighing errors for a 5 million tpa

operation for a bulk material with a value of US\$ 30/t. A good scale maintenance and calibration programme will pay for itself many times over.

#### Technologies available

Certifiable and process control scales need to be installed properly, maintained well, and calibrated frequently. Often, applications do not perform well because they are not installed properly, or are poorly maintained. In many cases, these problems (and the associated weighing errors) are not even recognised because of a lack of calibration and testing.

## Static and dynamic weighing systems

Weighing systems can generally be separated into two broad categories: static and dynamic. Static systems are weighing devices that weigh the material while at rest; dynamic weighing systems determine the weight of the commodity while it is in motion.

As static weighing systems determine the weight of material at rest, or in a state of equilibrium, the achievable weighing accuracy is generally higher than with dynamic systems. Even so, technology continues to improve, and many modern-day dynamic weighing devices can provide very acceptable weighing accuracies for custody transfer applications at a lower initial cost. However, time and resources needed for the ongoing maintenance, testing and certification of each of the types of weighing devices can differ significantly.

#### Common denominators

Regardless of the technology used, all scales have the following basic components:

- A surface upon which either the material or the container/vehicle holding the material rests (often known as the weighbridge), or a vessel that contains and captures the load (often known as a weigh bin or hopper). This component transfers the applied load to the weight-sensing elements.
- Weight-sensing elements that convert the mass sensed into a signal that can be interpreted.
- A weight indicator that captures the above signal and then displays the determined weight.

The weight-sensing element is very important. Today, there are three general types.

#### **Mechanical lever systems**

This is an older technology (but still widely used) based on the principles of a simple lever. A load applied on the scale platform produces a force at the end point of a series of levers proportional to the applied load.

#### Hydraulic/hydrostatic load cell

Hydraulic cells operate under the simple hydrostatic principle that load applied to a known area provides a known resultant output pressure. While not as common as lever systems and electronic load cells, these can perform effectively in many applications.

#### Electronic load cell

This most common weight-sensing element is a device that deforms under load, which then produces a small analogue electrical signal proportional to the applied load (Figure 2).

Today, digital load cell systems, which convert the traditional analogue signal to digital, are becoming widely used. The digital signal is more stable and less susceptible to outside interference, such as radio frequency and electromechanical signals. It can also travel further than its analogue counterpart, and the technology enables advanced troubleshooting capabilities. Many users are upgrading older scales to this technology.

#### Static weighing devices

In static weighing applications, the material only needs to be at rest long enough for the commodity being weighed to settle. Once a stable scale reading can be attained, an accurate weight reading is captured, and the process continues. All of the static weighing devices below can achieve weighing accuracies of  $\pm 0.1\%$ .

#### Truck scales

A truck scale is a widely used means of weighing material in vehicles (Figure 3). As the material is in the truck, it is already at rest. The truck itself comes to a full stop on a platform or deck (the weighbridge), typically constructed of some form of rigid structural steel, which is entirely supported by multiple (typically 8 - 10) load cells or a lever system. The force of the load is distributed over these weight-sensing elements and the signals are captured and summed to obtain the total weight.

Scale weighbridges range greatly in size according to the application. Many standard bulk commodity applications range from 20-m-long and 3-m-wide to 36-m-long and 3-m-wide.

While there are a number of variables that can affect prices, a completely installed truck scale costs approximatelv US\$ 40,000. In addition to its low cost, another advantage is that it can be located (or relocated) almost anywhere that a level grade can be found. However, it must weigh the material vehicle-byvehicle, which can be time consuming. For large tonnage operations, this can cause a bottleneck.

Testing and calibration of all types of truck scales is completed with calibration test weights. These are cast or fabricated blocks that are a known weight, calibrated in a laboratory, and traceable to known standards. Once these certified calibration weights are applied, the scale indication reads the applied weight, and the scale is adjusted to agree with the known calibration weight standard.

Calibration weights are not a part of the delivered truck scale hardware, but are transported to the scale whenever they are needed. As it is easily accessible by vehicle, the delivery of the calibration weights to a truck scale is not a problem. The use of calibrated, certified weight carts used in conjunction with test weights has become very popular in the US to facilitate a quick and economical method of testing and certifying rail and truck scales (Figure 4).

One important consideration when purchasing a truck scale is the ability of the weighbridge to withstand highly concentrated loads, generated by single, tandem or multiple adjacent axles groups, over the weakest area of a scale weighbridge. This is generally the mid-span area between load bearing sections of the scale.

While a truck's total weight may not exceed the scale's total gross capacity, it is possible that, due to the truck configuration and axle groupings, the truck may greatly exceed the concentrated load rating of a scale's weighbridge. If this is a frequent occurrence, the overall scale life will be adversely affected.





Figure 7. Components of a batch weighing loadout system. (Diagram courtesy of Kanawha Scales & Systems.)

As there are differences in the way in which scale manufacturers represent the concentrated load ratings on their scales, selecting the correct equipment requires a careful assessment of the stresses generated by the various truck configurations and axle groupings that need to be weighed. Inadequately sized equipment is a common cause of excessive scale wear and premature weighbridge failure.

#### Static rail scales

A static rail scale also weighs its cargo while at rest. In this case, it weighs a railcar while it is stable and stationary on a rail scale platform (Figure 5).

Static rail scales used for custody transfer are typically seen in one of three configurations: continuous length, single draft, or dual draft. Continuous length is very similar to a truck scale; there is a weighing platform, on which the railcar rests, which captures the weight with a series of load sensors. The single and double draft configurations utilise a modular weighbridge that is positioned directly under the axle pairing of the railcar. The single draft configuration uses two weighbridges and captures the weight of the car in one reading. The double draft uses only one weighbridge, therefore the railcar is weighed in two separate readings by capturing the weight of the first axle pairing and then adding the weight of the second.

An installed double draft static rail scale costs approximately US\$ 90,000. It is a very accurate way to measure bulk materials transported in rail wagons. However, the railcars must each stop completely in order for the weight to be captured, and it is therefore time-consuming. It is also costly to relocate, so it is important to get the initial location right.

Calibration and certification of rail scales is usually performed with specialised test equipment, which provides a known weight with which the rail scale is to be calibrated. These may essentially be the same as the test weights used for truck scales, except that more weight is required. Often, it is the railroads that own, maintain and dispatch this specialised equipment. As access to a rail scale is usually via the railway itself, a frequent complaint regarding rail scales is the logistical difficulty in scheduling the calibration unit to the scale. Specialised truck-dispatched rail testing equipment is becoming a suitable alternative for many rail scale installations.

#### Weigh bin scales

Weigh bin (or hopper) scales allow static weighing of bulk materials by collecting a 'batch' of material, capturing the weight, then subsequently discharging the weighed material. A weigh bin scale is typically a conical-shaped collection vessel, supported by or resting on three or four load cells. They achieve high accuracy in weight determination. These scales are much more costly than other static weighing devices, but they all combine important process control elements with their weighing function.

They also incorporate internal calibration weights so that scale accuracy can be verified within a few minutes. As they are static scales, they can be certified using these calibration weights (Figure 6).

#### **Batch weighing**

This system, sometimes referred to as a dosing scale, is commonly used in rail and



Figure 8. Diagram of pulse weighing system.

truck loading applications (Figure 7). In addition to accurately capturing the weight of a consignment, batch weighing also serves an important process control function by allowing the railcars and trucks to be loaded with a precise amount of material. By preparing a set amount of material for each rail wagon or truck, the loading function can be highly automated and efficient by filling the vehicle to the maximum allowable weight, without overloading or underloading.

A batch loadout system consists of the following common components:

- A feed conveyor to the top of the building provides continuous supply of bulk material to the loadout.
- A surge bin creates a buffer between the feed conveyor system and the batching process.
- High-speed weigh bin feed gates enable accurate batch preparation to a desired target weight.

The weigh bin scale captures the bin weight after it has been filled, and then again after being discharged, and records an actual loaded material weight. A weigh bin discharge gate releases material from the bin, through a chute, into the railcar or truck below. A typical cost of an installed batch weighing system is US\$ 1 - 1.5 million, but can vary significantly depending on the configuration.

#### Pulse weighing system

This is a dual weigh bin system used to provide static weighing while allowing the bulk material to continue to flow (Figure 8). The flow of material is cycled back and forth between two adjacent weigh bins and the consignment weight is the sum of the accumulated batch weights.



Figure 9. Model 10-14-4 precision conveyor scale. (Photo courtesy of Thermo Ramsey.)



Figure 10. Installation of a certified conveyor scale. (Photo courtesy of Thermo Ramsey and Kanawha Scales & Systems.)

The cost of an installed pulse weighing system is typically US\$ 550,000 - 750,000.

#### Garner system

This is similar to the other two systems, in that that total weight loaded is captured in discrete batches. The difference here is that there is an extra bin (called the garner bin) that provides greater control of the material's discharge once it is weighed, enabling efficient throughput with a single bin system. The garner system is used in direct vehicle loading applications and continuous material flow processes such as stockpiling.

#### Dynamic weighing systems

Dynamic scales for the bulk materials industries largely consist of two main types: in-motion railroad track scales and scales on conveyor belts. Achievable accuracies are generally less than static weighing systems due to the many different external forces that can affect the weighing system performance in dynamic applications.

#### In-motion rail scales

An in-motion rail scale is usually a single weigh module under a section of track (approximately 3.8-m-long). It captures the axle pairing weights in a dual draft mode of operation. Vehicle position sensors work with sophisticated electronics instrumentation to determine the weight of each individual car.

In-motion scales are configured for coupled or uncoupled in-motion operation. Uncoupled operations usually gravity-feed a car across a scale module in a controlled manner. Coupled in-motion (CIM) systems are more challenging, as the effects of the couplers tend to induce extraneous forces and stresses into the vehicle being weighed. Proper installation, location and foundation support are key to successful installations, as grade and track curvature can have significant impacts. An improper installation can be very expensive to fix or relocate.

An installed CIM rail scale costs approximately US\$ 150,000. Its advantage is the efficiency gained due to the ability to weigh the cars in motion. However, many different forces can disrupt its ability to perform, and locations available for a successful installation are limited.

The testing of CIM rail scales is a very complicated process that can be expensive. Unlike the individual test car used for the static rail scale, the CIM rail scale usually requires a test train consisting of a minimum of 10 cars, run over the scale at least five times in any of the four modes of weighing that it uses: pushing in either direction and pulling in either direction.

#### Conveyor belt scales

One of the most widely used devices for weighing bulk materials is the belt conveyor scale. As most bulk materials are moved over a conveyor belt at some point, this is a very convenient way to capture the weight for process control and custody transfer, without the need to interrupt the flow of material.

In its simplest form, a belt scale is a device that makes a determination of belt loading per length (i.e. kg/m), captures a belt travel rate (i.e. m/min), and then integrates this information into a weight per time. This rate of flow can then be totalised, so that an accumulated amount of material that has passed on a conveying system over the scale can be determined.

While there is a range of designs of belt scale systems, the typical belt scale system includes the same components as a static system, e.g. weigh frame, load-sensing elements and a data integrator, but has an essential additional sensor to determine the speed of the belt.

The weigh frame supports a set of idlers mounted on a frame (Figure 9). This structural frame is mounted to the conveyor structure so that the load imparted through the idlers is applied to the load-sensing elements (either a lever system with a load cell, or a series of load cells). The result is that as the conveyor belt travels over idlers, the load from the conveyed material on the belt exerts forces on these idlers and the weight-sensing elements. The weight reading on a known length of conveyor is matched with the conveyor speed to capture the weight of the material.

There are two major advantages of a belt scale. The first is its convenience, as the material is weighed while moving on the conveyor belt. The second is its cost; a certifiable belt conveyor scale fully installed costs approximately US\$ 42,000 and can weigh to  $\pm 0.125\%$  accuracy.

However, a belt conveyor scale requires a lot of attention in order to ensure its performance. In addition to the normal scale maintenance requirements, many parts of the conveyor belt can affect weighing accuracy.

In fact, it is essential to view the entire conveying system as part of the scale. Any forces that act on the conveyor and impede the scale's ability to sense only the forces from the material travelling on the conveyor belt can lead to poor weighing performance. This means that factors such as belt alignment, skirting, unrestricted rolling of idlers, training idlers, structural deflections and gravity take-up are important aspects of weighing with belt conveyor scales. Often, scales do not perform due to lack of attention to the conveyor system.

The location of a belt scale is also a critical factor. A frequent mistake in the application of conveyor belt scales is locating them in the wrong place (such as too close to a transfer or feed point).

Finally, conveyor belt scales are particularly susceptible to poor housekeeping. Material spillage is common with conveyor belts in general; most of the spillage in the area of the scale ends up on or under the weighbridge.

Many modern scales have the ability to perform an electronic calibration (called an E-cal or R-cal). This is often completed daily, but is not a check of the actual accuracy of the scale system (as is often assumed). Rather, it is simply a test of the stability of the electronics of the scale.

Another calibration technique is to use a known static weight, which can periodically be applied to the weighbridge. This weight allows a calibration of the weighbridge and load-sensing elements, but is limited because it does not take into account any of the effects of the conveyor belt movement and load distribution.

A more thorough calibration of a conveyor belt scale is called a chain test. Here, a roller chain, with a known (and properly sized) weight per unit of length, is placed on top of a running conveyor belt to simulate a material load on the conveyor in the area of the weighbridge. This is more complete because it takes into consideration the belt loading and conveyor influences such as alignment, tracking and belt tension.

Due to the complex effects of the conveyor forces on weighing accuracy, despite the above calibration methods, the only way for a belt conveyor scale to be certified in the US is by conducting a materials test. This test requires passing a prescribed amount of material, which is weighed before or after on a separate scale that has itself been certified within 24 hours, over the conveyor scale. This can be expensive and logistically complicated and is a significant disadvantage of belt conveyor scales.

#### Conclusion

There are many options available when it comes to the weight determination of bulk materials. Static weighing systems generally provide higher accuracies than dynamic systems, but the stated accuracy of any scale is only achievable with proper installation and ongoing care. This includes special emphasis on housekeeping and calibration maintenance. Payment for any bulk material should only be done on a scale that is both certifiable and certified.

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