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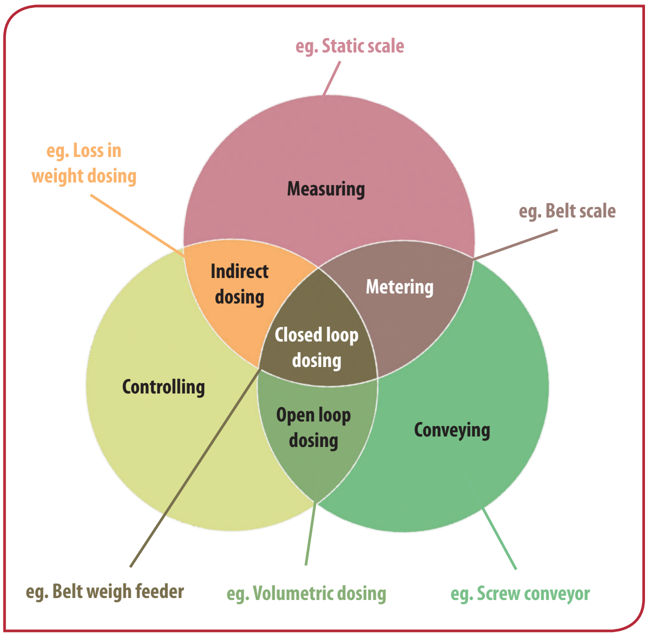
A framework for the classification of bulk material dosing equipment in the cement sector

The metering and dosing of bulk materials is a key task in the cement sector and, even though many different system architectures have been used, there has been no systematic classification available until now. This article proposes a general taxonomy for the classification of metering and dosing devices for bulk material to aid decision-making.

The transport and logistics systems used in the cement sector are driven by strict requirements regarding the accurate dosing of bulk materials. The equipment used must be carefully considered and requirements will vary depending on the point in the process where the equipment is used. Furthermore, it needs to vary greatly from the quarry to the bagging plant in terms of scale and the types of material being dosed.

The materials to be dosed may be powdery, granular, flaky or fibrous, may flow freely or be cohesive and will have different densities. All of these factors affect the type of equipment that should be used to dose them. It is also important to consider the long-term stability of the aforementioned characteristics, which is often underestimated during the design phase of bulk material handling systems. Also important are the legal requirements that need to be fulfilled, for example in the dosing of fuels.

Even if the above factors are taken into account there can be no guarantee that the selection and integration of the optimal corresponding dosing equipment can be completed successfully. A typical example is the transfer of positive or negative experiences with a particular piece of equipment from a specific application to a completely different scenario. This is a common trap in the conceptual phase of engineering projects and runs contrary to a logical and rational selection of the optimal equipment.



Right - Figure 1: A classification of dosing systems based on three basic functional elements.

Classification of dosing devices

The three main functional elements of typical dosing devices are measuring, conveying and controlling. The combination of either any two or all three of these basic elements defines the specific character of the equipment (See Figure 1). From this Venn diagram, we can name five different classes of machines as a general taxonomy for the proportioning of bulk materials. The exact definition and corresponding aspects are summarised within Table 1. All are justified within their specific applications as there is no suitable piece of equipment that can meet the needs of all different applications.

Breakdown of equipment

1. Pure measuring devices – Silo scales and weighing hoppers are typical examples of pure measuring devices. They are mainly used in order to determine actual filling in terms of weight and/or volume (in the case of bulk material with constant density and humidity). The mass of the material is measured by means of a set of load cells, mechanical mounting modules for effective force transmission and an evaluation unit. Figure 2 shows a typical example.

2. Differential systems - Differential or indirect dosing systems typically consist of a silo scale or weighing hopper that is equipped with a controllable discharge system. A screw, for example, is used to discharge a hopper, which is placed on a set of load cells. These measure the actual material weight within the hopper. By using the loss-in-weight principle the actual

Device	Measuring	Metering	Indirect dosing	Open loop dosing	Closed loop dosing
Description	The volume or weight of the material is measured and used to define the amount at a given time	The material is conveyed with a certain conveying speed and at the same time the massflow is determined based on a measured weight	The volume or weight of material is measured. At the same time a separate conveying system is controlled in order to achieve a certain volume or mass flow	The conveying speed is controlled based on a pre-defined calibrated relationship in order to achieve a pre-determined volume or mass flow	The weight or volume and the conveying speed are measured to calculate the mass or volume flow. The conveying speed is continuously controlled in order to achieve a desired mass or volume flow
Measured values	Mass (kg), Volume (m^3)	Speed (m/s), Mass (kg)	Speed (m/s), Mass (kg)		Speed (m/s), Mass (kg); Mass flow (kg/hr) or Volume flow (m^3/hr)
Control variables			Mass flow (kg/hr) or Volume flow (m^3/hr)		Speed (m/s); Mass flow (kg/hr) or Volume flow (m^3/hr)
Type of operation		Continuous	Discontinuous	Continuous	Continuous
Type of dosing			Gravimetric	Volumetric	Gravimetric
Example	Silo scale	Belt scale	Loss-in-weight system	Screw conveyor with pre-defined relationship between volume and screw speed	ODM-WeighTUBE®

Left - Table 1: Overview of different dosing, metering and weighing devices.

mass flow (kg/hr) can be continuously calculated by taking into consideration the mass difference within a defined time interval. By changing the screw speed it is possible to achieve a desired mass or volume flow.

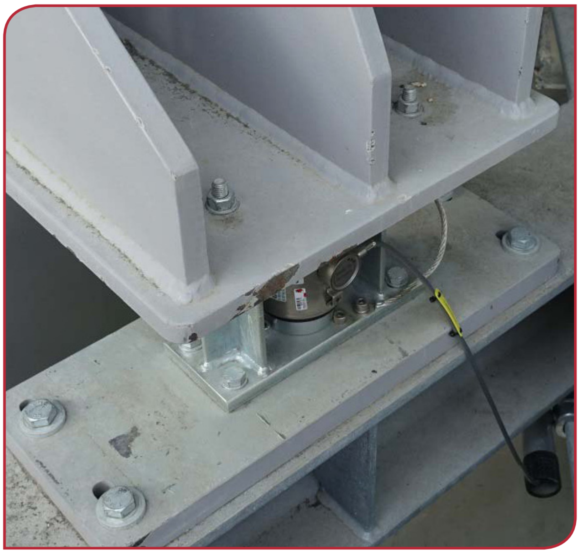
The main drawback of this setup is the missing possibility to dose the material continuously, as one cannot know the weight lost if material is constantly entering the same receptacle. This means that differential systems are only suitable for batch-type dosing.

3. Metering - The process of metering of mass flows consists of a standard conveying system such as a belt or screw conveyor and the determination of the actual flow by means of an integrated weighing system. A typical belt scale consists of a belt conveyor that transports material with a certain speed to a single weighing roller, which determines the actual belt load. From the measured belt load it is possible to compute the mass per length unit, which can be used to determine the mass flow. A standard metering device contains no control circuit at all, as it only computes the actual mass flow. There is no feedback to alter the speed of the conveyor.

"Avoid the 'status-quo decision-making trap,' which can be prevalent in conservative industries such as cement manufacturing..."

Open-loop dosing - Open-loop dosing is also known as volumetric dosing. Its main principle is the operation of a certain conveyor with a certain pre-defined speed for each possible mass flow set-point. Thus, the actual weighing of the real material is neglected and instead it is assumed that, for the generation of a constant mass flow, it is sufficient to generate a constant volume flow. This assumption is only valid if the bulk density of the material is constant.

As there is no information of the actual mass flow from a gravimetric measurement unit, it is necessary to define a calibration curve or generalised mathematical relationship in order to define the



Left - Figure 2: A typical load cell module for silo scales or weighing hoppers.

dependency between the actual speed of the conveyor and the mass flow. In most cases volumetric dosing is realised by a screw conveyor, since the use of a trough or tubular screw conveyor guarantees a quite stable volumetric feeding behaviour for different speeds compared to, for example, a belt.

However, for materials that have variable properties over time, (such as humidity or density as is the case with alternative fuels) for the accurate dosing of alternative fuels, an open loop dosing method is not applicable.

5. Closed-loop dosing – The most sophisticated and accurate solution for the dosing of bulk materials is closed-loop dosing, also known as gravimetric dosing. This is because the actual mass flow is determined by an integrated weighing unit.

The actual conveying speed is measured by, for example, an incremental encoder and, along with the material load, it is evaluated constantly. There is direct feedback from the calculated mass flow to the variable speed drive unit. If there is a deviation between the actual mass flow and the desired set-point, the actual conveying speed can be adapted. Thus, high precision is guaranteed. The maximum deviation from the set-point is <2%.

However, the operation of classical belt weigh feeders, as shown in Figure 5, in practical applications is characterised by two main aspects: First of all, belts are by nature non-closed systems. This leads to non-negligible dust emissions and spillage of material, which affects the measurements taken by the scales. Secondly, many existing dosing methodologies suffer immensely from time-variable material properties. This leads to a non-negligible drift in the dosing accuracy over time. Thus, belt weigh feeders need to be manually re-calibrated on a regular basis, as often as once a month, in order to guarantee long-term stability. These two issues led Di Matteo to develop a completely novel closed-loop dosing system: the tubular weigh feeder ODM-WeighTUBE®.

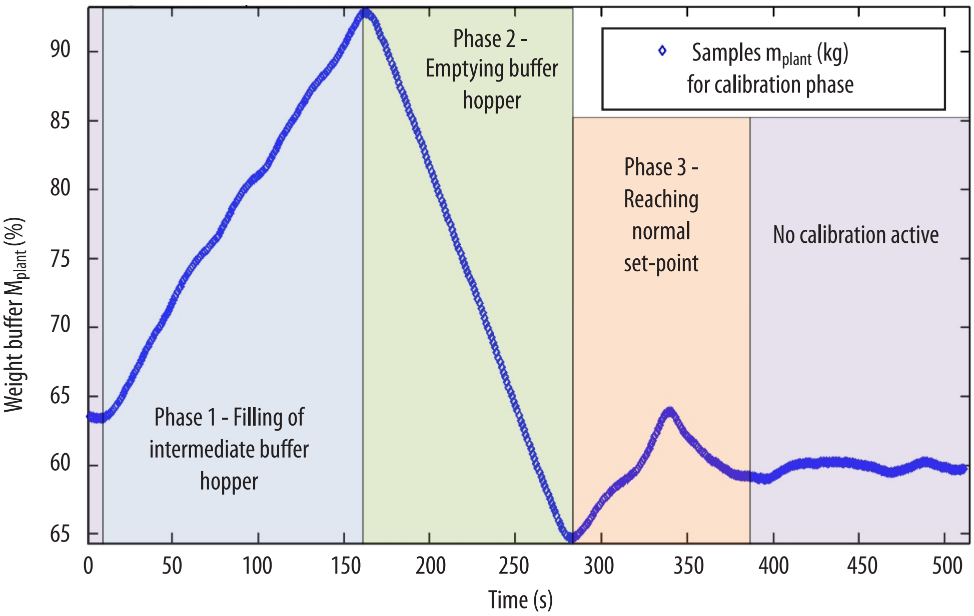
The ODM-WeighTUBE®

The ODM-WeighTUBE® was introduced in 2010. Although many of its early installations focused on problematic bulk materials, such as refuse-derived fuels (RDF), the system has since been used in cement plants for a range of other materials, including raw meal, fly ash, iron ore and clinker. Around 100 units now operate in the global cement industry.

Figure 3 shows the ODM-WeighTUBE® RWS series, which includes three models (RWS 500, RWS 400 and RWS 250). The selection of the individual model depends on the type of bulk material and the intended dosing range.

The general dosing principle is similar to the classical closed-loop scheme. The ODM-WeighTUBE® consists of a tubular screw conveyor, which continuously discharges material from an intermediate buffer. The material is conveyed to the tube section, which is placed on a set of load cells that are de-coupled from the main frame of the machine by flexible connections. It is therefore possible to measure the actual material weight within the tube. Furthermore, the actual conveying speed of the screw is constantly monitored. Both physical values are processed in order to calculate the actual mass flow. By taking into consideration the desired mass flow (set-point) it is possible to determine the actual deviation, which is fed to the continuous dosing controller (CDC). The CDC adapts the screw speed in order to minimise the deviation under all circumstances and at any given time. All software elements are implemented within

Below - Figure 4: The ODM-WeighTUBE RWS series.



Left - Figure 4: The three phases of the ODM-WeighTUBE's calibration routine.

the ODM-GravitAS control system. This system was developed by Di Matteo as a unified platform for all of its weighing and dosing applications.

Furthermore, the ODM-GravitAS control system implements an automatic calibration routine, which provides the possibility to estimate properties of the dosed bulk material and automatically adapt the controller parameters in such a way that the dosing accuracy remains stable over time. The actual process operation is not influenced by performing the automatic calibration routine, so that the available machine time can be increased. During the automatic calibration routine the intermediate buffer hopper of the ODM-WeighTUBE is filled to a pre-set maximum. In the second phase the buffer hopper is emptied by normal dosing operation as no further material enters it, up to a predefined minimum buffer weight. From the resulting difference in mass and the corresponding expired time, the actual control parameters of the continuous dosing controller are automatically adapted.

To avoid possible undesired influences, all controller parameters are checked for plausibility based on a probabilistic analysis of former calibration cycles, before they become active in the system. A typical calibration process, with its three phases, is shown in the Figure 4, where the actual buffer weight m_{plant} (kg) is shown changing with time.

The decreasing buffer weight in the second phase of the calibration process is almost completely linear, which indicates constant material throughput. A possible deviation between the actual and the desired mass flow during this phase is evaluated for the probabilistic adaption of the controller parameter. The possibility for a continuous on-the-fly auto-tuning of the controller depending on the given material properties is a very important element for long-time stability and accuracy of the gravimetric dosing.

By the combination of the ODM-WeighTUBE® platform with the GravitAS control system a high dosing precision of <±1% related to the nominal throughput can be guaranteed.

Summary

This article introduces a framework for the systematic classification of dosing and metering equipment for cement plants and relative industries. The defined taxonomy allows a better understanding of the exact nature of a certain type of equipment and can be used as a guideline during the design and implementation of system setups.

An important aspect of the selection of adequate dosing equipment is to avoid the 'status-quo decision-making trap,' which can be prevalent in conservative industries such as cement manufacturing. This can have severe consequences on the competitive situation of many organisations, because it might happen that technological developments are adopted too late or even neglected entirely.

Below - Figure 5: The ODM-GraviSCALE belt weigh feeder.