SIEMENS


**PROCESS INSTRUMENTATION**

# The "black magic" of **solids flow measurement**

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Walking through your Portland cement plant, you see a huge amount of equipment every day. Conveyor belts, pressure and temperature measuring devices, filter systems, additive dosing machinery—the list goes on and on. Take solids flowmeters: you know what they do, how to fix them (or who you should call to fix them!), but have you ever wondered how they work?

Don't be fooled by their apparent simplicity—material goes in, material comes out, you get a measurement. But what's really going on inside a solids flowmeter? The answer will change the way you think about this piece of equipment as you walk past it each day.

### First, the process

After the journey from the quarry to grinders and the kiln, the final step in the process of making Portland cement is the finish mill. Clinker, along with a proportional amount of gypsum, is fed into the mill to be ground into finished cement ready for storage or transportation. The design of a finish mill generally consists of a very large diameter steel tube filled with a designated quantity of steel grinding balls. As the mill is rotated at an optimum speed, the grinding balls crush the clinker/gypsum mixture into a fine powder.

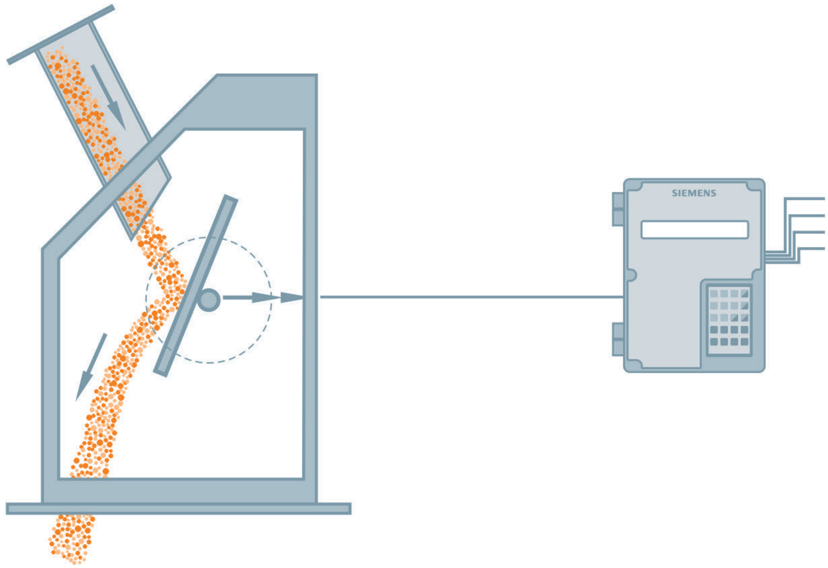
A high-efficiency cyclone separator controls the particle size. The drum is generally divided into two or three chambers with differently sized grinding media. As the clinker particles are ground down, smaller media are more efficient at further reducing the particle size.

In a closed-circuit system, coarse particles are separated from the finer product and returned to the start of the process for further grinding. This is called a recirculating load, and to ensure peak efficiency, the mill should run with an optimum load.

The most common application for a solids flowmeter here is the coarse returns downstream from the cyclone separator. It is important that this reading be instantaneous, since the load of the mill needs to be maintained at a level to achieve the most efficient grinding. With this rate feedback, the system controller can vary the input of clinker and additive feeds to quickly adjust for the best grinding control. The flow rate in the coarse return process varies from system to system, but rates of up to 800 t/h (880 STPH) are possible.

### The impact of impact-based flowmeters

The most reliable solids flowmeters available are impact based. These flowmeters have an impact plate mounted at an angle that the material strikes as it flows down, continuously from one point to the next. The flowmeter sensing element - either load cells or an LVDT-based mechanical assembly - measures the impact force generated by the flowing material and converts this data into an electronic signal. This signal is converted into a mass flowrate with a very repeatable accuracy.




The principle of an impact-based flowmeter is as follows: when solid material is gravity fed from a chute or pipe at a height (h), the horizontal component of the impact force generated at the plate (F0) is proportional to the mass flow rate (G) of the material. The free body models shown in Figure 1 illustrate this principle, and the following equations are obtained.

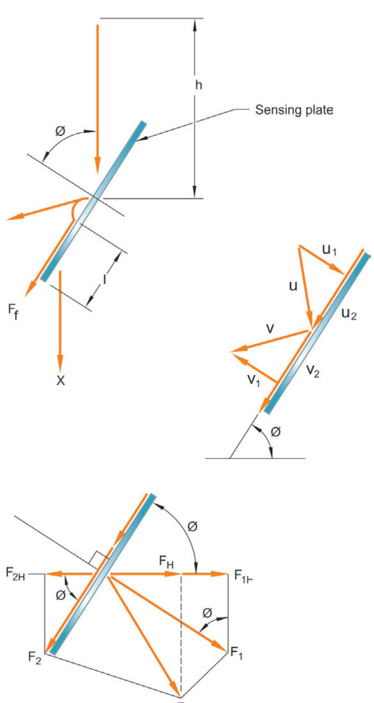



**Figure 1**

The horizontal force applied to the sensing plate in applications with material buildup is calculated using the following equation:

$$F_H = F_{1H} - F_{2H} - F_{fH}\alpha G$$

If height (h), the angle at which the impact plate is inclined (θ), the distance material flows down on the sensing plate (l), and material properties are constant, total horizontal force applied to the impact plate is proportional to the mass flow rate (G) of the material.

Gravity is vertically exerted at angle θ, and a horizontal force is not included in the calculation. Friction between free flowing particles and the sensing plate generates force (Fr), which is applied to the plate in the direction in which the particles flow. If the coefficient of friction between particles and the plate does not change, the force is related to the number of particles that flow (X). The horizontal component (FrH) of this force (Fr) is calculated using the following equation:

$$F_{fH} = Xucos\theta = G\frac{lu}{v}.cos\theta$$

where u = coefficient of friction.

In applications where particles hit the sensing plate and flow onto it, some may remain on the plate (material buildup). Weight (X) of such particles is calculated using the following equation:

$$X = G\frac{l}{v}$$

where l = distance that the particles have moved on the plate

v = average velocity at which particles flow on the plate

The horizontal force applied to the sensing plate ($F_H$) is calculated using the following equation, based on the horizontal component of $F_1$ ($F_{1H}$) and $F_2$ ($F_{2H}$).

$$F_H = F_{1H} - F_{2H} = \frac{A-B}{2}G\sqrt{\frac{2h}{g}}\,sin2\theta$$

**Horizontal component ($F_{1H}$) of the vertical force ($F_1$)**

The vertical force applied to the plate ($F_1$) is calculated as follows, taking momentum into account:

$$F_1 = \frac{G}{g}u_1(1+\frac{v1}{u1})$$

where u = velocity of impact applied to the sensing plate

v = resultant velocity of sensing plate to initial position

Assuming that

$$\frac{v_1}{u_1} = e$$

where "e" is defined as the coefficient of restitution.

Taking air friction into account, and using coefficient "k" (0<k<1), impact velocity "u" is as follows:

$$u_1 = k\sqrt{2gh}$$

Therefore, the vertical force component will be:

$$F_1 = k(1+e)G\sqrt{\frac{2h}{g}}cos\theta = AG\sqrt{\frac{2h}{g}}cos\theta$$

where θ = angle of inclination
Coefficient A = k(1 + e)

The horizontal component $F_{1H}$ is calculated using the following equation:

$$F_{1H} = F + 1sin\theta = k(1+e)G\sqrt{\frac{2h}{g}}cos\theta sin\theta$$

Horizontal component ($F_{2H}$) of the force parallel to the plate ($F_2$)

The following equation is obtained in the same manner as above.

$$F_2 = \frac{G}{g}u_2(1-\frac{v2}{u2})$$

Assume $v_2/u_2$=B. This is the coefficient mainly due to friction.

$$F_2 = k(1-b)G\sqrt{\frac{2h}{g}}sin\theta = BG\sqrt{\frac{2h}{g}}sin\theta$$

where coefficient B = k(1-B).

Therefore, horizontal component $F_{2H}$ is calculated from the following equation:

$$F_{2H} = F_2 cos\theta = BG\sqrt{\frac{2h}{g}}sin\theta cos\theta$$

The advantage of impact technology is that the drift due to the mechanical stability of the assembly is eliminated. Only the horizontal force is measured, so material buildup does not affect the output or zero reading.

There are two ways of implementing the solution. One involves using an LVDT (linear variable differential transformer) sensor mounted in a frictionless pivot assembly, shown in Figure 2.

The other option is to use load cell technology. Load cells offer a very cost-effective solution for impact-based flowmeters, and in fact are used in a variety of solutions such as Coriolis and centripetal designs as well. The ideal load cell option is a parallelogram style cell, which operates in the same way the LVDT assembly does above in that it does not react to vertical forces, but only horizontal ones due to material impact. Material buildup is also negated with a load cell design.

**Impact force considerations**
Impact force is classified in grams per tons per hour (tph). The use of grams as a force is intentional to equate the force component into a weight value and is also used in calibration mass calculations. With a steady flow of material at one ton per hour, the typical impact forces of materials are shown below:

| Material | Impact force (per tph) |
|---|---|
| Milk powder | 21 g |
| MSG | 25 g |
| Middle bran | 30 g |
| Sand | 36 g |
| Pellet | 45 g |
| Nominal | 45 g |

To establish a basis for calculating flow force, multiple materials were tested and an average or nominal value was established for a given free fall height and sensing plate angle. It is important to note that if any of these variables change, the resultant impact force will also change. This is similarly true of the material itself: if the characteristics of the material such as moisture content or impact absorption changes, so too will the impact force.

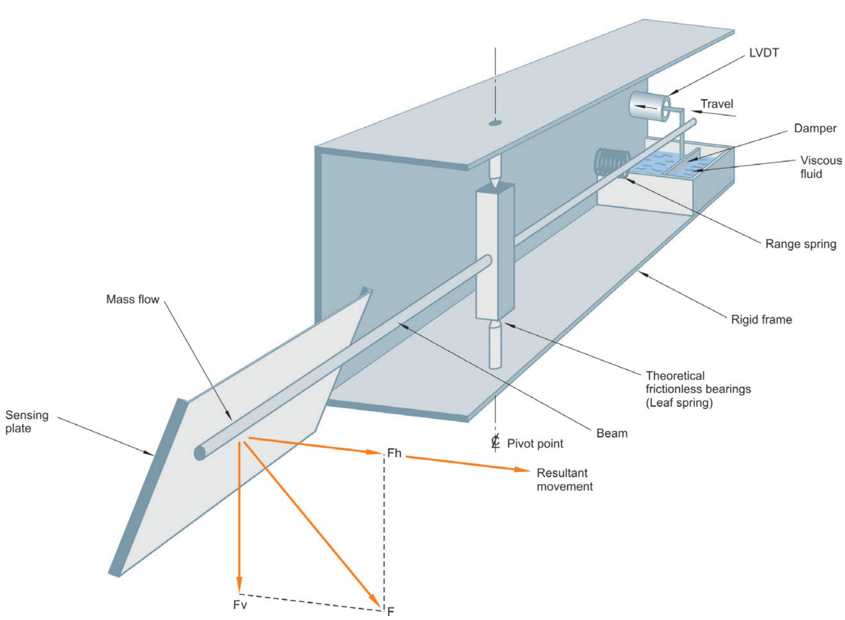
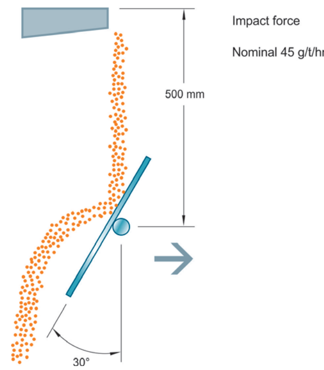



**Figure 2**




The 45 g/tph force value can be compared to placing a 45 g calibration weight on the LVDT assembly and measuring the deflection of the plate due to this change through the pivot and spring assemblies. The horizontal component of the impact force on the sensing plate is directly proportional to the flow rate of the material over the plate. The angle at which the material strikes the sensing plate is also very critical for proper operation—the combined angle of the flow guide and sensing plate should not exceed 60° or be less than 50°.

As shown in Figure 3, the horizontal force acts against a compression spring, through a set of frictionless bearings and is converted into a horizontal movement (deflection). Transients are “smoothed” out in a viscous damper and the movement is converted into an electrical signal for integration.

**Accuracy in cement manufacturing**
The accuracy of an installed flowmeter system will depend primarily on the product being handled and the feed system to the flowmeter. The flowmeter relies on a constant velocity of impact, so it is essential that materials are always dropped from the same height.

In the cement industry and with similar material, accuracies of around +/-0.5 to +/-1.0% are fairly common. Table 1 shows typical results of linearity tests carried out at the factory. Table 2 shows the results of tests carried out on a system where a screw conveyor was being used to feed cement to a flowmeter.

**What does this mean in the field?**

Setting our sights beyond the physics classroom, let's see how all of these equations are being put to work.

Take St. Marys Cement in Ontario, Canada. In every way, St. Marys is a modern cement production facility, with an output of approximately 1.2 million tons of Portland cement each year. Automation along with instrumentation controls and maintains processes throughout the plant.

St. Marys has depended on Siemens weighing technology for more than 30 years. And in many cases, the company has depended on the very same weighing devices that were installed 30 years ago.

St. Marys uses the E-300 solids flowmeter with an ILE-61 sensing head to monitor the coarse returns of the finish mill below the separator. Both devices are still offered by Siemens as the SITRANS WF330 flowmeter and SITRANS WFS320 sensing head: new names and colors - but precisely the same design and high degree of functionality.

As stated earlier, impact flowmeters like SITRANS WF330 have several distinct advantages over other types of flowmeters. First, these devices can handle very low to very high flow rates—ideal for monitoring the finish mill's coarse returns. Secondly, their accuracy and repeatability are not affected by material buildup on the sensing plate, as we saw above, since only the horizontal force of impact deflects the sensor. Any additional weight that results from material sticking to the plate does not shift the output of the system.

Table 1:

| Test weight (g) | Theoretical indication | Actual indication | Error: % reading | Error: % reading |
|---|---|---|---|---|
| 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 600 | 0.800 | 0.801 | 0.125 | 0.025 |
| 1200 | 1.600 | 1.603 | 0.185 | 0.075 |
| 1800 | 2.400 | 2.405 | 0.208 | 0.125 |
| 2400 | 3.200 | 3.204 | 0.125 | 0.100 |
| 3600 | 4.000 | 4.000 | 0.000 | 0.000 |

Table 2:

| Actual flow | Indicated flow | Error: % reading | Error: % full scale |
|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 |
| 4.00 | 4.03 | 0.75 | 0.15 |
| 8.00 | 8.07 | 0.875 | 0.35 |
| 12.00 | 12.10 | 0.833 | 0.50 |
| 16.00 | 16.05 | 0.312 | 0.125 |

Also decades ago, technicians installed a COMPU-FLO integrator, which was then replaced by a COMPU-M integrator. As time progressed, St. Marys replaced this device with the Milltronics SF500 integrator. The Milltronics SF500 offers online calibration as well as standard industrial communications protocols like Modbus, Devicenet, and Profibus DP.

With this combination of flowmeters and integrators from Siemens, plant operators receive precise rate-of-flow measurements instantly without having to interrupt the flow of material—a definite plus for busy Portland cement plants like St. Marys.

**The physics of reliability**

Now that you've taken a peek behind the curtain to see the physics on which a solids flowmeter is based, these devices may no longer seem so mysterious - or perhaps they are now even more mysterious.

We know, however, that it's really not about the math—it's about providing a reliable measurement for process control and quality. What appear to be at first glance somewhat unsophisticated devices are actually vital components for producing Portland cement. Anywhere the flow of material needs to be measured, solids flowmeters are there: from mill recirculating loads as discussed above to kiln dust monitoring, loadout to trucks, rail or ships, and measuring kiln feed.

But take it from someone who walks past these devices every day: when speaking about the weighing devices installed throughout St. Marys Cement, Electrical Supervisor Kevin Hodgins simply states: "They just work."

They certainly do—and now you have the math to prove it.

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