Variable amplitude vibrator provides tighter control

Challenges of regulating dry product flow succumb to motor-drive-gear algorithm

FAST FORWARD

- Chutes are the transition elements between a feed bin and the conveyor system.
- Random step changes in loading render PID ineffective.
- The eventual control algorithm is complex and not mathematically continuous.

By G. Paul Baker

Dry material whether powdered, clumped, stranded, or pelletized, usually feeds into a reactor, blender, or kiln by means of a conveyor belt.

The entire feed system works so specific amounts of material enter the receiving vessel at a regulated rate.

Often, bulk material is stored in a feed hopper or bin and from there transfers directly onto the conveyor belt. If deposition is relatively uniform, the feed can be regulated either in a batch mode by starting and stopping the conveyor, or by regulating conveyor speed for continuous feed.

In each application, the characteristics of the dry materials determine whether achieving an even deposition on a conveyor is easy or difficult.

Important characteristics are the density of the material and its average, minimum, and maximum clump (or pellet) size. Also considered is the particle's stickiness (adhesiveness to itself and to the sides of a bin or chute), moisture content, the angle of friction, and the angle of repose (the angle at which a conical pile of the material will become stable—i.e. stop sliding down). These characteristics combine to produce another parameter, which may be important depending upon the design philosophy used—the natural or resonant frequency.

If the material is dense, has a relatively uniform particle size, and a large angle of repose, equalized deposition of material can be achieved onto the conveyor by means of the design of the mouth of the feed bin.

An offset, rectangular mouth, cut so the edge on the direction of movement of the conveyor is at the desired height of the material should work nicely.

If the material has a relatively small angle of repose and displays little adhesiveness, a closable gate at the mouth of the feed bin, coordinated with the motion of the conveyor, should be able to accomplish an even deposition of material on the belt.

However, in most real-world applications, variations in material characteristics are large and somewhat random, with differences occurring due to sources of material, local ambient conditions, environmental factors, and so on. This fact limits the ability of a fixed design to regulate material feed.

Weight systems can be a part of the conveyors, providing a continuous view of the amount of material in one specific area of the belt, typically between a pair of rollers.

Variable speed motors can regulate the conveyor speed to allow manipulation of the belt speed to accommodate varying amounts of deposition. This approach can be effective in slow moving processes.

However, the mass and inertia of a typical conveyor system prevents it from responding to rapidly varying loads. Here, the conveyor is the final control element. Its slow response would not allow the use of ordinary control algorithms.

The designer's task, then, is to provide some uniformity to the material loaded onto the belt,

Vibrators held at natural frequency

The image shown here is a typical chute installation used to transition between a feed bin and a conveyor belt.

Moving from left to right along the chute, the first component is the chute pivot axis, about which the chute can rotate as it vibrates. The pivot axis and all other components mount on the feed chute backbone. This provides a rigid system to mount the components and effects a more even distribution of the vibrations into the more flexible feed chute.

Next, to the right of the pivot axis, is the drive motor, followed by the reducing gearbox. The drive motor provides the power to drive the system, while the reducing gearbox will bring the rotational speed of the drive motor down to the resonant frequency of the material.

To the right, is the angular motion translator (AMT), shown with its actuator, and an analog positioner. Next are the dual, concentric output drive shafts and a dual weight shaker assembly.

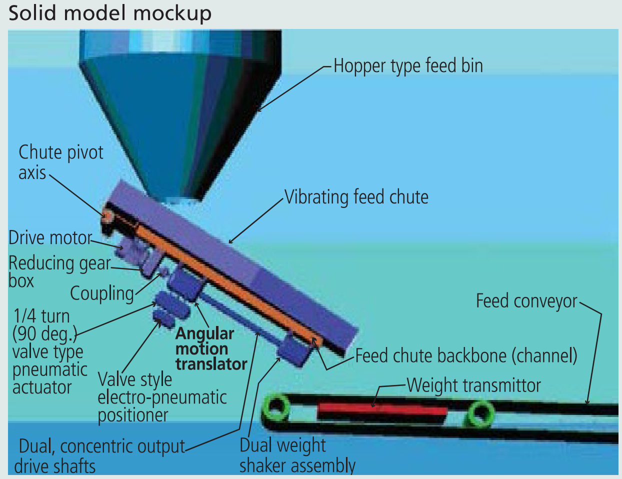
Not shown is the equipment to dampen the movement of the chute, to limit the movement to acceptable maximum excursions, and to cause the chute to idle at a median position between the positive and negative excursions.

The mouth of the chute feeds directly onto the feed conveyor. The point of transition on the feed conveyor is equipped with a weight transmitter.

In overall concept, the intent is to use the weight transmitter as the primary element and the AMT/shaker assembly as the final control element.

The AMT is a patented device that allows an angular relationship in two parts that are not in rotation, to replicate in two other components that are in rotation, all with completely mechanical connections.

Solid model mockup



Source: Angular Motion Technologies

so the conveyor speed can be relatively stable.

Hefty challenges for PID

Frequently, feed chutes are the transition elements between a feed bin and the conveyor system. The intent is to manipulate a characteristic of the chute to achieve a uniform deposition of material on the conveyor.

There are many chute designs that manipulate the geometry of the chute, at the opening of the feed bin, at the mouth feeding the conveyor, or by changing the slope of the chute.

These can be effective, but usually have difficulties with varying material characteristics. If, for instance, the size of the throat area of the chute mouth serves to control deposition, and the material is somewhat sticky, the effective throat size will vary as material agglomerates around the mouth, and again when the clods break through to the conveyor.

Random step changes in loading, such as the above, would prevent the use of standard proportional-integral-derivative (PID) control.

Friction between particles of the material, and between particles and the surfaces of the chute, have the effect of holding the material stable, until reaching an "angle of friction" (AoF). The angle of friction is usually greater than the "angle of repose" (AoR) and is typically about 4 degrees.

Chutes designed to use the AoR and the AoF, attempt to regulate feed rate by changing the angle of the chute. Once the AoF is past and flow has started, a constant rate of feed is possible by holding the chute angle between the AoR and AoF.

However, in these applications, the coefficient of friction between the material and the chute surfaces is not constant, and it will increase with a reduced rate of flow and with changes in moisture content. Additionally, the depth of product will decrease as it accelerates down the chute, also affecting the coefficient of friction.

While it is possible to configure actuators to rapidly change the chute angle, this approach has inherent problems associated with hysteresis (the inertia of the material works against both increasing feed flow and decreasing feed flow, but in opposite directions), and also with variations in this characteristic of the material.

The control algorithm is very complex and not mathematically continuous. This presents significant challenges for PID control. Also, since there will need to be a fairly rapid angular movement through the average AoR and AoF, the tossing about of the dry material in an open top chute will create more spoil than equal deposition.

The most controllable chute designs do not depend specifically on the characteristics of the material to control flow. Rather, they attempt to use the characteristics to hold the material in a static state and inject mechanical energy at specific points to cause the material to move. In chute design, this typically takes the form of some sort of vibrator, shaking the material at the mouth.

Changing the vibration

The various characteristics of the material will have an impact on its natural, resonant frequency.

If mechanical energy injects into the material at this resonant frequency, most of the energy goes to moving the material.

Vibrator details

The shaker assembly consists of two eccentric mass weights fitted around a common axis. The eccentric mass of each of these weights are identical, such that, when the weights are exactly opposed (180 degrees out of phase), they will counterbalance each other.

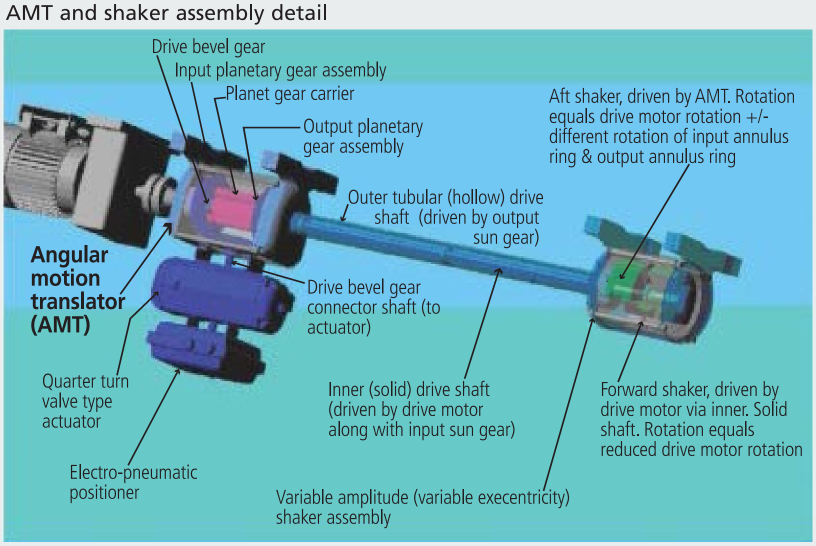
Under this condition, there will be no net eccentricity and no vibration occurs. In the alternative extreme condition, when both eccentric weights align exactly, precisely in phase, the maximum eccentricity will be present and the maximum amount of vibration produced.

These eccentric weights each connect to their own output shaft. The forward shaker runs directly off the drive motor through the reducing gearbox, by means of the inner, solid drive shaft. The aft shaker runs off the outer, hollow drive shaft, which in turn runs off the output sun gear of the angular motion translator (AMT).

The function of the AMT, then, will be to drive both the inner and the outer output drive shafts at the speed of drive motor's reduced RPM and then add or subtract 180 degrees of rotation from the outer drive shaft.

This will allow the aft shaker to move, in a continuous controlled fashion, from being exactly in phase with the forward shaker (maximum, 100% eccentricity) to being exactly 180 degrees out of phase with the forward shaker (minimum, 0% eccentricity).

AMT and shaker assembly detail



At points above and below this frequency, more of the energy will convert to heat or serve to break up particles, which also converts the energy to heat.

Rotary vibrators generate a sinusoidal vibration and therefore are much more efficient in bringing dry material into resonance, and holding it there, than linear vibrators. Because, linear vibrators produce a square wave motion in which the energy spreads over a spectrum of up to nine harmonics, the energy present at the natural frequency of the material will always be weak and diffused.

Furthermore, with rotary vibrators, the frequency of vibration is adjustable using variable speed drive motors to accommodate changing characteristics of the material.

But, when a variable speed drive is used as the sole means of controlling material flow, the drive will be operating outside of the resonant frequency most of the time, and therefore in a less efficient range.

What we need is some method of changing the amplitude of the vibration while holding the frequency of vibration within a narrow range. This is where the angular motion translator (AMT) finds a most useful application.

The AMT consists of two mirrored planetary gear systems with their planet gears connected to a common planet gear carrier. The two-annulus gears of the planetary sets have beveled teeth cut into their outer edges, both driven by a common gear called the drive bevel gear.

As this drive bevel gear rotates, the annulus gear of one of the planetary gear sets will rotate in one direction, and the other annulus gear will rotate by an equal amount in the opposite direction.

At times when the drive bevel gear is not rotating, both annulus gears remain stationary.

The output of the reducing gearbox rotates the inner, solid drive shaft through the coupling, and rotates the sun gear of the input planetary gear assembly; this sun gear fixes to the inner output shaft. As this sun gear rotates, it causes the planet gears of the input assembly to rotate against the stationary annulus gear, and these cause the planet gear carrier to rotate. The rotating planet gear carrier forces the output planet gears to rotate against the stationary annulus gear of the output planetary gear assembly.

These output planet gears in turn cause the output sun gear to rotate at the same speed as the input sun gear. The output sun gear drives the outer tubular drive shaft.

While both annulus gears are held stationary, both the outer and the inner drive shafts will rotate at the same speed, namely at the speed of the output from the reducing gearbox.

The drive bevel gear connects by means of the connector shaft to a stan-

The AMT consists of two mirrored planetary gear systems with their planet gears connected to a common planet gear carrier.

Terminology

PID: A proportional-integral-derivative controller is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly

Hysteresis is a property of physical systems that do not instantly follow the forces applied to them, but react slowly, or do not return completely to their original state.

dard, quarter-turn, valve actuator. Since the drive bevel gear rotates an annulus gear in one direction, and the other annulus gear in the opposite direction, the rotation of the drive bevel gear doubles up during its application to the two-annulus gears.

The various ratios between the drive bevel gear, the two-annulus gears, and the two sun gears are such that a 90-degree rotation in the drive bevel gear will produce a 180-degree change in angular relationship between the outer drive shaft and the inner drive shaft. This allows the standard quarter-turn actuator to control 180 degrees of phase change between the aft shaker weight and the forward shaker weight.

The actuator runs off instrument air. An industrial electro-pneumatic positioner regulates the position of the output from the actuator, and therefore the drive bevel gear. This positioner accepts a 4-20 milliamp input and regulates the air pressure provided to the actuator. This allows the drive bevel gear to remain always between 0 and 90 degrees, corresponding to the level of the 4-20 milliamp input.

The phase relationship between the two eccentric weights will therefore be exactly set between their two extremes, that is, completely in phase (maximum eccentricity) and exactly out of phase (minimum eccentricity).

In applying these concepts to chute design, the goal is the vibrator controls all movement from the chute to the conveyor belt. This means the overall chute angle must be below the angle of repose of the material.

Using an opened throat Feed Bin, material should flow from the bin into the chute until the material in the chute chokes off the mouth of the bin. The material should remain stationary in the chute until the vibrator causes the material at the outlet of the chute to plop onto the conveyor.

This removal causes the slope at the bottom of the chute to exceed first the angle of repose, then the angle of friction. Material will then flow down the chute, clearing the throat of the bin, and allowing more material to flow.

When a continuous, steady state flow is achieved, the average angle of material at the outlet end of the chute will be between the angle of friction and the angle of repose, with the flow controlled by the amount of material being bounced onto the conveyor by the vibrator.

Since in this application the speed of rotation of the vibrator is at the resonant frequency of the material, the transfer of energy to the material should always be in its most efficient zone and should maintain a clean, proportional relationship between the amplitude of eccentricity and the amount of product deposited onto the conveyor.

With a weight transmitter on the conveyor acting as the primary element and with the AMT shaker assembly as the final control element, any industrial standard PID controller will control the flow of dry material onto the conveyor, allowing an even deposition of product.

The success here is this system will provide a proportional relationship between amplitude of vibration and deposition of material, and thus should allow the use of standard, industrial, PID control algorithms.

ABOUT THE AUTHOR

G. Paul Baker (gpaulbakerjr@cox.net) is an ISA senior member. He holds the patent on the AMT technology (www.angularmotiontechnologies.com). He has been active in industrial instrumentation, control, and safety systems in the petrochemical industries for over 35 years.

View the online version at www.isa.org/intech/20080303.

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