How to manage impact forces in your dense-phase pneumatic conveying system

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Low-velocity plug flow is a method of dense-phase pneumatic conveying that handles granules or pellets of fairly uniform shape and size. System throughput over 50,000 lb/h and conveying distances over 1,000 feet are becoming more common for this conveying method. And when equipped with high-pressure rotary valves, a plug-flow system can operate continuously without using a pressure vessel.

But the plug-flow method has an unavoidable side effect: the impact forces produced by the plugs. This article explains how you can manage the effects of these forces so they don’t cause system components to fail or impair your system’s reliability. After covering some pneumatic conveying basics, the article discusses the problem of impact forces, common mistakes that can increase impact force effects, and how to minimize the effects in your conveying system.

Before discussing how you can manage such effects in your conveying system, let’s review how plug-flow dense-phase conveying works and what causes the impact forces.

Some pneumatic conveying basics

Dense phase is one of three pneumatic conveying phases, as shown in the example phase diagram in Figure 1. The dilute-phase region has relatively high transport velocities (typically 3,000 to 7,000 fpm) and low, stable operating pressures. The system’s high turbulence suspends the material in the flowing airstream. You can use this conveying phase to handle almost any material. Dilute phase also lets you use a broad range of conveying velocities with little effect on the operating pressure level or its stability.

Lower conveying velocities and erratic operating pressures characterize the unstable region. The reduced turbulence in this region allows some particles to fall out of suspension and accumulate in layers. In turn, material plugs can form at occasional and unpredictable intervals, causing the operating pressure to surge and resulting in a high material acceleration rate. (Conveying phases are material- and system-specific, and the Figure 1 phase diagram is only an example. Diagrams for other materials or systems can differ; for instance, some very fine powders are so easily fluidized that their phase diagrams may not include an unstable region.)

In some dense-phase pneumatic conveying methods, granules or pellets move through the pipe in plugs, which is called plug flow. When accelerated, the plugs impart dynamic impact forces to the pipe. If you don’t manage the effects of these forces, your conveying system’s components can fail and the system’s operation can become unreliable.

In contrast, the plug-flow dense-phase region has relatively low conveying velocities (typically 400 to 1,800 fpm) and relatively high, stable operating pressures. The lack of turbulence allows all the material to accumulate in layers. As the layers build up, they form plugs at a relatively frequent and predictable rate, as shown in Figure 2.
In this type of conveying, you must accurately control the conveying velocity to avoid both the unstable region (at right on Figure 1) and the minimum air velocity limit (at left). By controlling the conveying velocity, you'll also achieve better control of the operating pressure and its stability.

Using plug-flow dense-phase conveying minimizes particle degradation that can occur in a dilute-phase system's relatively high conveying velocity and turbulence. Thus the plug-flow method allows you to transport granules and pellets, which are sensitive to degradation. This conveying method is limited to uniformly shaped granules or pellets.
with an average particle size larger than \( \frac{1}{6} \) inch and a narrow particle size distribution. Examples include plastic pellets, such as polyethylene, polyethylene terephthalate, and acrylonitrile-butadiene-styrene; foods; grains; and some prilled chemicals.

The problem of impact forces

As a plug is accelerated in the conveying system, it collides with other plugs, pipe elbows, and diverter valves, as shown in Figure 3. These collisions impart impact forces to the pipe, vibrating it. The forces' frequency and magnitude depend on several factors. They include:

- **Force magnitude**: The magnitude of the force, \( F \), is a function of the plug's mass and acceleration — \( F = f(ma) \).

- **Mass**: The plug's mass depends on the plug frequency — the lower the frequency, the higher the plug mass.

- **Frequency**: The plug frequency depends on the pipe diameter — the larger the pipe diameter, the lower the plug frequency (indicated by greater plug length), as shown in Figure 4.

- **Acceleration rate**: The plug's acceleration rate depends on the material characteristics — a hard, slippery material such as high-density polyethylene will accelerate faster, and an elastic, sticky material such as low-density polyethylene will accelerate more slowly.

- **Size**: Plugs can be as long as 30 feet and weigh up to 600 pounds. The longer and heavier the plugs, the greater the impact forces.

Common mistakes that increase impact force effects

If you don't understand how the factors affecting the impact forces interact, you can make various mistakes in selecting or installing your conveying system equipment or in operating the system. These errors can increase the effects of impact forces on your system and, if left uncorrected, eventually lead to serious equipment and production problems.

For instance, improper equipment selection or installation can cause mechanical failures in pipes, structural supports, pipe fixtures (such as the clamps or bearings that fasten the pipe to the structural supports), other system components (such as knife gates and diverter valves), and silos. Damage to this equipment can disable and even destroy your conveying system. And operating the system at higher-than-optimal velocities can not only increase equipment wear but increase material degradation.

Following are the mistakes most likely to increase impact force effects in the system.

**Poor pipe routing.** Poor pipe routing can be the beginning of the end for the conveying system designer. Using multiple elbows in sequence or long incline pipe sections prevents the system from ever achieving stable operation. A pipe routing with long, unsupported pipe sections or without adequate rigid structural supports can never be sufficiently restrained from vibrating.

**Incorrect choice of pipe components.** Choosing a component with a short service life — such as a flexible hose or thin-wall aluminum pipe that can jerk or shake strongly as plugs impact it — will cause frequent mechanical failures and increase maintenance headaches.

**Improper pipe sizing.** If you choose the wrong pipe diameter, the system may never achieve stable operation. Operating in the unstable region (Figure 1) will shorten the life of all pipe components.
Sloppy installation. Poor equipment installation can defeat a good system design. During a sloppy system installation, misaligned pipes can prestress pipe connections, which may not be checked later. The installer may also forget to tighten bolts or properly isolate the pipe from a weak connecting structure, such as a silo nozzle. These mistakes can increase impact force effects and cause system components to fail.

Poor operation. An undertrained operator who changes system operating parameters without consulting your system designer can compromise even a well-designed and -installed system's operation. For instance, if the conveying system plugs and shuts down, an operator may decide to increase the system airflow to get the system running again so the entire plant isn't shut down. If not done properly, increasing the airflow can cause conveying to move into the unstable region, which can increase impact force effects.

Poor maintenance. Failing to make regular system inspections can lead to equipment problems. For instance, without regular inspections, the operator may not notice loose fasteners, a common side effect of the vibration. Failing to notice and tighten loose fasteners can lead to loose pipe clamps and bearings, which can't restrain the vibrating pipe. Using low-quality pipe and other system components can also increase your system's maintenance requirements.

System changes. You can compromise even a well-functioning system's operation if you make a system change without consulting the system designer. Examples include adding a conveying destination, switching to a different bulk material, or changing capacity. Such a change can alter the system's operating requirements and impair the system's operation.

How to minimize impact force effects
Working closely with the system designer can help you design a plug-flow system that minimizes the effect of impact forces. The designer typically works for a conveying system supplier or an independent engineering and con-

![Figure 3](image-url)
Know your material. Make sure the system designer has complete information about the handling characteristics of each material the system will handle. For instance, a family of material grades can exhibit a wide range of handling characteristics, but without knowing this range the designer can’t design a system to handle all the materials. Expect to conduct tests to characterize each material.

Also ask what kind of experience the system designer has had with the same or similar materials and request a reference list of the designer’s system installations. If the designer has no related experience, ask the designer to conduct conveying tests of your material before designing the system.

Properly route the pipe. Make sure the system designer knows where your conveying system will be installed in your plant, the location of other equipment, and other factors that will affect the pipe routing. For best results, the designer should visit your plant before planning the system. A piping isometric diagram, as shown in Figure 5, can be prepared by you or the designer. The diagram pro-
vides a three-dimensional view of the pipe routing and will help you not only plan the routing but install the system later.

The optimal pipe routing should:

- Minimize the total conveying distance.
- Minimize the number of pipe elbows.
- Avoid multiple elbows in sequence.
- Avoid incline pipe sections or minimize their length.
- Allow the pipe to be strongly anchored to the plant foundation (even if this increases total pipe length).
- Include no flexible hoses.

Properly select the pipe diameter. Once you’ve characterized your material and properly designed the pipe routing, the system designer can help you choose the optimal pipe diameter — and, hence, conveying velocity — by using pneumatic conveying calculations based on factors mod-
After selecting the pipe diameter, the system designer can help you select the pipe material, wall thickness, and inside diameter as well as appropriate system components such as gates and valves. Then the designer will calculate the system’s pipe forces, which include the pipe’s static loads, the pipe’s thermal expansion, and the dynamic loads imparted by the plugs’ impact forces. The calculation helps the designer summarize loads at each pipe section so you can select pipe clamps and bearings and determine where to place them.

**Ensure the pipe is properly supported.** Depending on your pipe diameter, you can use one of two methods to ensure the pipe has enough support. If your pipe diameter is less than 6 inches, you can rigidly fix the pipe to a structural support, which can typically absorb the forces.

If the pipe diameter is 6 or more inches, the pipe forces can become so strong that using adequate rigid structural supports may be impractical or too expensive. In this case, you need to reduce the impact forces transmitted to the structural supports, either by reducing the magnitude of the impact forces or by isolating these forces from the system’s supports.

One way to reduce the forces is to reduce the plugs’ average mass. You can do this by increasing the material-to-air ratio (ratio of mass flow of product to mass flow of air) in the system. A system with a smaller pipe diameter generates shorter average plug lengths at a higher frequency, as shown in Figure 4. This means that the average plug in a small-diameter pipe will have less mass. However, because decreasing the pipe diameter requires using a higher material-to-air ratio, the operating pressure also increases. As a result, this way of reducing pipe forces is limited by your system components’ allowable operating pressure or the air supply’s minimum available pressure, or both.

Another way to reduce the plugs’ average mass is to redistribute or split the plugs by installing a device to break them up. Such a device is available in various types from multiple conveying system suppliers. One proprietary device receives each plug and splits it into smaller plugs, thus reducing the impact forces. When installed correctly in a new or existing system, the device can reduce the forces by more than 50 percent.

You can also isolate or dampen the impact forces by attaching the pipe to the structural support with elastic bearings, which are typically made from synthetic rubber and are available from multiple suppliers. To determine what size to use and where to install the bearings, you need to analyze your piping isometric diagram, your system’s operating parameters, and your material’s handling characteristics. Once the elastic bearings are in place, they can reduce the impact forces by as much as 60 percent.

**Properly install the system.** Installing the conveying system correctly can be more important than its design. In fact, overcoming system design errors often requires improvising at the construction site. But if your system design has been carefully executed, be aware that even a minor revision to the planned pipe routing can compromise the system’s operation. For instance, if the installer adds two or more elbows to reroute the pipe around existing process piping, the original pipe supports may become unsuitable for the revised arrangement.

Discuss any potential revisions to the original design with the system designer. Because installers’ skill levels vary, you can save excessive reworking by supervising and periodically inspecting the installation. The designer (or the designer’s representative) should also plan inspections during system installation.

**Use adequate system controls.** To avoid an upset condition that can cause the plug-flow system to operate in the unstable region (Figure 1), you must adequately control the material and airflow. Even a carefully designed system can operate unreliably if it’s poorly controlled.

You’ll need a control system with sophisticated program logic to handle the array of operating parameters in a dense-phase conveying system with multiple conveying distances or that handles multiple materials with different handling characteristics at multiple or variable throughput. The control system may be available through the conveying system supplier, or the supplier can help you program your plant’s processor to control the conveying system’s operating sequence.

You can optimize the control system with analog measurement and control instrumentation. Equipping the system to handle real-time and historical trending of the system’s material and airflow measurements can also help your operator start up and troubleshoot your conveying system.

**Follow proper startup procedures.** Make sure that the system designer (or the designer’s representative) is present at your system’s startup. Prior to startup, thoroughly check all the control functions and alarms. During startup, the designer will fine-tune the system’s operating parameters — particularly the airflow controls — to ensure the system operates at the optimal level.

**Train your operator.** During startup is the best time to train your system operator (or operators). By participating in and observing the startup, the operator will learn trou-
bleshooting basics. To get the maximum benefit from your system designer’s on-site visit, also have the designer lead classroom training sessions for the operator before, during, and after startup.

**Practice adequate maintenance.** Because of the plug-flow conveying system’s high material-to-air ratio, excessive air leakage through critical components such as diverter valves, rotary valve seals, butterfly valve seals, and pipe flanges can impair the system’s reliability. Good maintenance practices, including checking and replacing these components at intervals recommended by the system supplier, will help you prevent excessive air leakage.

**Reference**


**Sources**


**For further reading**

Find more information on this and related topics in articles listed under “Pneumatic conveying” on pages 104-105 of *Powder and Bulk Engineering*’s comprehensive “Index to articles,” December 1997.

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