This two-part article explains how to use venting to improve the rotary valve feedrate to your pneumatic conveying system. Part I discusses how leakage occurs in a rotary valve, how to predict leakage flow, and how to determine your venting needs. Part II, scheduled for the November 1997 issue, covers types of rotary valve vents, discusses selecting a passive or active vent system, explains how to troubleshoot vent system problems, and describes venting solutions in several case studies.

A common yet poorly understood problem with pneumatic conveying systems is inadequate rotary valve venting. The problem is most likely to occur when the rotary valve feeds material against higher pressure, but can also occur when there’s no pressure differential across the valve.

A rotary valve, as shown in Figure 1, typically feeds dry, free-flowing bulk materials between fluid atmospheres (typically at different pressures) that must be more or less isolated from each other. [Editor’s note: For more information on rotary valves, see the related sidebar, “A review: Rotary valve basics.”]

What makes the rotary valve so useful for feeding material in a pneumatic conveying system is its simplicity, ruggedness, durability, relatively low cost, and simple control requirements. But the price you pay for these desirable features is the valve’s less-than-perfect isolation of the fluid atmospheres — in a word, leakage.

Gas leaking from the rotary valve into the material feed hopper (or other vessel) can greatly impair the valve’s feeding efficiency, especially if the material is easily fluidized. The leakage gas flows upward into the overhead feed hopper, counter to the material’s downward flow into the valve. The gas can reduce the material’s bulk density or even suspend the material at the valve inlet. The result can be a slower feed rate, intermittent feeding, or even a feeding halt.

Figure 1

Typical rotary valve (with drop-through housing)
You can control leakage by installing a vent (as part of a vent system) that will capture and redirect the leakage flow away from the material in the hopper. This will prevent the rotary valve feedrate from dropping below the valve’s theoretical capacity (which is based on the valve’s material displacement and rotor shaft speed). But before discussing vents and vent systems, let’s take a look at how leakage occurs in a rotary valve, how to predict leakage flow through it, and how to determine your venting needs.

How leakage occurs
Two rotary valve characteristics contribute to leakage from one side of the valve to the other:

- There must be clearance between the rotor (that is, the vane tips) and the valve housing (called rotor-housing clearance). This creates clearance leakage.

- The rotary valve isn’t a positive-displacement device, so if a rotor pocket is exposed to pressure at discharge, that pressure stays in the pocket until it reaches the valve inlet. This produces displacement leakage.

Clearance leakage. The total amount of clearance leakage depends on four factors: the rotary valve size, pressure differential across the valve, amount of rotor-housing clearance, and rotor design. Some clearance is not only necessary for the rotary valve’s reliable operation, but is typically unavoidable. But to minimize leakage, a rotary valve is designed with minimal clearance.

To specify rotor-housing clearance, the rotary valve manufacturer’s design engineer has to select a clearance small enough to limit leakage but large enough to prevent rotor-housing contact in all likely operating modes. The factors to consider include:

- Unequal thermal expansion of the rotor and housing due to changing process temperatures. (The rotor is typically lighter weight and has more surface area exposed to the process than the housing, so the rotor expands more rapidly when exposed to high temperature.)

- Internal clearance and runout in rotor support bearings.

- Rotor deflection caused by pressure differential.

- Housing and end flange deflection caused by pressure differential forces acting on the rotor and transmitted through the rotor support bearings.

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**A review:**

**Rotary valve basics**

A rotary valve, as shown in Figures 1 and 2 in the accompanying article, can be applied as a feeder to volumetrically meter material from bulk storage, in which the material fills the valve to its capacity. The valve can also be used as an airlock to pass material from one atmosphere to another at a rate less than the valve’s full capacity (in this case, between 40 and 60 percent of capacity).

The rotary valve consists of a rotor fitted with multiple vanes that turns inside a cylindrical housing. For a feeding or metering application, the rotary valve installs below a feed hopper (or other vessel) and above the material pickup point in a pneumatic conveying system. A material inlet is at the rotary valve’s top or side and an outlet is at the bottom. The rotor shaft is supported by bearings and powered by a motor.

**Operation**

In a rotary valve with a drop-through housing, which is most common, a fixed volume of material flows from the hopper into the top inlet. In a side-entry housing, the material enters the side inlet.

In both housing styles, the material enters a rotor pocket formed by two adjacent vanes. As the rotor turns, the material in the pocket is carried downward to the bottom outlet, where the material drops into the conveying system. The rotor’s rotation brings the empty pocket back up to the inlet, and the cycle repeats.

**Clearance**

The rotor-housing clearance (also called the vane- or blade-housing clearance) is the distance between a vane tip and the housing wall along the rotor sides and ends. The clearance can be adjusted to limit leakage through the valve while avoiding contact between the rotor and housing.

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The arrangement and number of rotor vanes also affect clearance leakage. In all rotor types, the vanes have a labyrinth seal (multiple-barrier) effect around the rotor's circumference. But only the vanes in the open-end rotor type, as shown in Figure 2a, have a labyrinth seal effect against the housing ends. In the closed-end (shrouded) rotor, as shown in Figure 2b, the end plate (called a shroud) at either end of the valve housing provides only one leakage barrier rather than the multiple barriers provided by the open-end rotor. For this reason, an open-end rotor with the same rotor-housing clearance, operating under the same pressure differential, and with the same number and size of vanes as a closed-end rotor will often have less leakage than the closed-end unit.

**Displacement leakage.** Four factors — the pressure differential across the rotary valve, rotor pocket volume, material feedrate, and rotor shaft speed — determine total displacement leakage. Because the rotary valve doesn't provide positive displacement, particles entering an empty rotor pocket must displace an equal volume of gas. If the pocket is exposed to pressure while emptying, the pressure remains sealed inside the pocket until it reaches the valve inlet. At that point, excess gas is released from the pocket into the feed hopper until the pocket pressure equals the gas pressure at the hopper bottom.

**How to predict leakage flow**

To determine total leakage flow through your rotary valve, add the clearance leakage flow to the two components of displacement leakage flow: the material displacement leakage flow per unit time and the pocket gas expansion leakage flow per unit time.

**Clearance leakage flow.** To predict clearance leakage flow in your rotary valve, you can use a common formula for calculating gas flow through circular or infinite-aspect-ratio rectangular orifices. The formula typically is used for predicting subsonic gas flow (flow slower than the speed of sound) in pneumatic conveying applications. But the formula yields good leakage flow estimates for vent system design, even when the absolute pressure ratio across the rotary valve exceeds the critical absolute pressure ratio.

The formula is:

\[ Q = K \cdot A \cdot (\Delta P)^{0.5} \]

where \( Q \) is leakage flow in standard cubic feet per minute (scfm), \( K \) is a combined coefficient for various gas characteristics (as shown in Tables I and II), \( A \) is usually taken as the valve rotor's plan view perimeter length \( 2 \cdot (\text{length} + \text{diameter}) \) in inches multiplied by the nominal rotor-housing clearance in inches, and \( \Delta P \) is the pressure differential across the rotary valve in pounds per square inch.

From the formula, you can see that the clearance leakage flow is a linear function of clearance. This illustrates how important it is to maintain close internal valve clearances. For instance, only a 0.001-inch increase in average clearance in a rotary valve with an original 0.005-inch clearance increases leakage flow by 20 percent.

**Displacement leakage flow.** Calculating the material displacement leakage flow is simple: Divide the feedrate in pounds per minute by the solid (not bulk) density of the material in the feed hopper.

To predict the leakage flow from pocket gas expansion, you need to know the rotor's working volume and speed.
and the pressure on both sides of the rotary valve. Use the ideal gas law to calculate the net excess gas volume picked up by the empty rotor pocket on the rotary valve’s high-pressure (inlet) side and released on the low-pressure (outlet) side. Assuming a constant process temperature, this gas law is:

\[ Q_{excess} = \text{rpm} (V_2 - V_1) \]

where \( V_2 = \frac{P_1 V_1}{P_2} \)

where \( Q_{excess} \) is the calculated leakage gas flow from pocket gas expansion in actual cubic feet per minute.
(acfm) at $P_2$, rpm is rotor revolutions per minute, $V_2$ is the total volume of expanded gas in the rotor in cubic feet, $V_1$ is the rotor displacement per revolution in cubic feet, ($V_2 - V_1$) is the net volume of gas expanding outside the rotor per revolution, $P_1$ is the higher absolute pressure per square inch (psia), and $P_2$ is the lower absolute pressure in psia.

How to determine your venting needs

**Considering venting during valve selection.** When selecting a rotary valve to feed a column of material (that is, feed under a material headload in a feed hopper or other vessel) into a positive-pressure pneumatic conveying system, assume the valve requires venting to release the leakage gas from the valve before it can back up into your feed hopper. This is especially true if your material is a powder.

When selecting a rotary valve that will operate as an airlock (that is, without a headload above it), you may not need to vent the valve. (In such a case, however, you may need to specify an oversize valve to compensate for the material’s lower bulk density.)

**Considering venting after valve installation.** If leakage flow causes feeding problems after you install a rotary valve, you can add venting (or replace the valve’s existing venting). But make sure you’ve identified or eliminated other potential problem sources first.

For instance, a uniformly low feedrate or a fluctuating rate between the desired feedrate and low feedrate (particularly when the valve feeds material into a positive-pressure pneumatic conveying system) can indicate a worn rotary valve as well as a need for venting. In such a case, be certain the rotary valve isn’t at fault before assuming the venting is inadequate.

Other problems only appear to be venting-related. For instance, feeding can slow or stop when the material forms an arch or rat hole in a poorly designed feed hopper. Or the feedrate can fluctuate simply because the material is extremely cohesive.

Some leakage problems are the result of handling a certain material under particular operating conditions. For instance, if your rotary valve must feed a very fine powder that has low gas permeability, you can experience feedrate problems that require venting even if there is no pressure differential across the valve. Gas displaced by the material alone can cause feedrate problems if that gas can’t get away from the valve’s inlet.

To diagnose a feedrate problem with a rotary valve that’s been installed for years, consider the period over which performance has changed. Has the valve (or conveying system) always performed this way? Or has the performance deteriorated over time? And have your material’s characteristics changed over time?

A long-term performance change often indicates a problem other than a need for venting. For instance, rotary valve wear can reduce the feedrate over time, which requires you to rebuild or replace the valve. And a change in your material over time from pellet- or granule-size particles to powder-fine particles can reduce the material mass's permeability and increase its fluidizing tendency, which can affect feeding efficiency.

**Considering solutions in addition to venting.** Be aware that in addition to solving leakage problems with venting, you may need to reduce the leakage at its source. If you have a difficult-to-handle material or need to minimize leakage flow because the differential pressure is very high (as in a continuous dense-phase pneumatic conveying system), you can use a reduced-leakage rotary valve. Special end-seal rotary valves can reduce clearance leakage by approximately 50 percent.

You can also use a rotor with more vanes, which increases the labyrinth seal effect by reducing clearance leakage, in turn reducing the pressure differential across each vane tip. If you have a constant-temperature application so the rotor isn’t subject to thermal expansion, you can use a “zero-clearance” rotary valve, which has a non-galling, self-lubricating rotor material that makes an extremely tight rotor-housing clearance practical.

**Next month:** In Part II, find information on types of rotary valve vents, selecting a passive or active vent system, how to troubleshoot vent system problems, and venting solutions in several case studies.

**Reference**


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