Vacuum Conveying of Dense Metal Powders

By Nick Hayes, Volkmann Inc.

Additive Manufacturing, aka 3D printing, is a rapidly growing business sector with new machines, models, developments, and more complex components being added on a daily basis. As the production rates increase, the need to be able to supply raw materials to the machine and to reclaim/reprocess excess materials from the molding box give rise to the need for an efficient, contained, and safe method of handling the various powders associated with the additive manufacturing (AM) process.

While this is true for all such methods of additive manufacturing, it is particularly significant when considering the use of metal powders, which have inherent issues that need to be addressed in order to run a successful manufacturing operation. Whether the components being manufactured are simple models or complex aerospace components, as the rate of production increases, the demand for more time being devoted to the actual manufacture will increase. As a result, there will be less time available to devote to the unloading of the build box and rework of the excess material. However, the need to safely and efficiently handle the powders only increases, and finding methodologies to address these concerns becomes critical to overall success of the operation.

Vacuum receiver cross section illustrating discharge

The Issues to Overcome

The essential issues to be addressed in the transfer of metal powders in an additive manufacturing process are:

- Containing transfer from the bulk material storage delivered from the powdered metal suppliers
- Avoiding the cross contamination of the metal during transfer
- Avoiding explosion risk
- Having the ability to clean the system during changes of material
- Having the ability to transfer material with a bulk density as high as 600 lb/cu ft
- Needing to unload, screen and return the material to use
- Having the ability to work in an inert atmosphere

These issues are further complicated by the production requirements in the actual transfer process:

- Virgin metal powder must be loaded into the AM machine hopper
- Excess material from the build box gets transferred to a screener for removal of oversize metal
- Screened material is returned to the AM machine hopper
- Addressing the possibility of blending virgin and screened return-to-use material in some yet-to-be defined proportion

Then there is the situation where one needs to transfer material from a build box that has been removed from the AM machine and positioned in an unloading station.

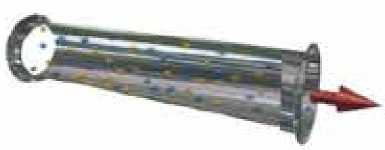
How Vacuum Conveying Addresses Concerns

When it comes to conveying heavy bulk density metal powders, two issues present themselves immediately. First, will the flow of air pick up the material and convey it in the airstream (the so-called saltation velocity)? If not, will the vacuum pump have sufficient ability to overcome the material weight and convey in dense phase plug flow?

Vacuum conveying can successfully meet the needs of additive manufacturing operations using metals by providing a contained, effective, and safe method for the metal powder transfer. However, like many processes, and indeed AM machines, not all vacuum conveying systems are created equal. The simple domestic vacuum cleaner with which we are all familiar is a vacuum conveyor of sorts. However, we all understand its limitations and, for example, we know it cannot pick up that coin or paperclip that we dropped on the family room floor.

Vacuum receiver - tangential separation

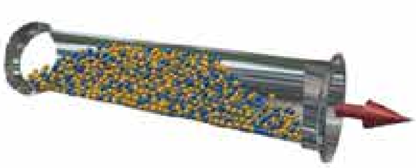
In simple terms, it is what is known as a lean phase conveying system. In these systems, and in most vacuum conveyors that use a fan or regenerative blower as the motion source, the velocity of the air used for transfer is high typically somewhere between 4000 and 6000 ft/min (for reference 5400 ft/min is 60 miles per hour). At these velocities, erosion of the conveying line and excessive wear of the conveyor are common. Typical vacuum levels generated in these systems are in the 7 to 9 in. of mercury below atmospheric range. This type of conveying typically leads to another problem – namely the segregation of particle size.



Dilute Phase Conveying

Velocity w = 4000 up to 6000 ft/min
v/w < 1
μ = 10 (...30)
w = air velocity
v = product velocity
Qs = product mass flow
Ql = air mass flow
μ = product load = Qs / QL

To avoid such issues, it is necessary to reduce the velocity of the air or gas stream. As the velocity drops, product falls from the air or gas stream and deposits on the lower section of the conveying line, increasing the level of vacuum generated. This continues as the velocity drops until the conveying line effectively becomes blocked. To avoid this, vacuum levels should remain at 18 to 20 in. of vacuum and a point where a plug of material will be transferred in dense or plug flow.



Plug Conveying

w = 750 to 1500 ft/min
v/w < 0,5
μ = 10 – 100

The resultant conveying is dense phase, low velocity, avoiding the segregation and abrasion issues of the lesser systems.

An essential element of the dense phase conveying is the vacuum receiver. High-quality, modular designs with filters down to 0.3 microns and secondary HEPA filters allow for simple cleaning and quick changes in the metal powder. Extensive testing using both a patented vacuum pump and the alternate rotary claw type electric vacuum pumps coupled to the vacuum receiver have proven effective with the wide range of dense metal powders.

For inert conditions, conveying a closed-loop system is used where the exhaust gas from the vacuum pump is recirculated to the pickup point. Monitoring for the oxygen level occurs during the conveying process.

Load, Unload, Successfully Screen and Return-to-Use Metal Powders with High Bulk Densities at High Rates

As mentioned, the ideal conveying process for metal powders in additive manufacturing will load the AM machine, unload the build box, and return the material to use after screening. Screening of surplus material from the build box is carried out to remove agglomerates with acceptably sized particles returning to the AM machine. Some discussion is occurring within the industry as to whether this can be 100% of a build, or some proportion blended with virgin use material.

This screening process can represent a bottle neck in the process in so much as the rate of screening is likely to be less than the rate of conveying and or the rate of use of the material. Typical screen sizes are 45, 63, and 105 microns, depending on the application. Both vibratory screening and ultrasonic screening have been used, with the latter achieving higher throughputs in testing. Various metal powders have differing screening rates with aluminum tending to be on the lower end of the range and stainless steel powder at the higher end. Other materials tested include Monel, titanium, Inconel, H188 chrome alloy, silver, cobalt, and tungsten.

Combining the unloading conveyor and screener into a single "harvesting station" with the optional ability to return the material to the AM machine, all within a contained safe explosion proof environment, is currently available in the Volkmann AMMHAS units.

Also under development are standalone unloading stations that allow the build box to be removed from the AM machine and taken to unloading and screening. This, in turn, provides the ability for a second build box to be running the manufacture of a component while the first unit is being unloaded, thereby increasing overall productivity.

Conclusion

As the rates of production increase in this rapidly emerging manufacturing sector, as they surely will, the issue of handling large volumes of powder during process development will become increasingly difficult. Applying good material handling practices will become even more critical.

Inert harvesting station

Non-inert harvesting station

Nick Hayes is president of Volkmann Inc., Bristol, PA *which engineers and manufactures high-performance vacuum conveyors, including the AMMHAS line for additive manufacturing, bulk bag unloaders, bag dump stations and equipment for the contained, gentle and damage-free transport of powders, granules, pellets, tablets, food particles and small components for the additive manufacturing, chemical, pharmaceutical, and food industries. For more information, call 609-265-0101 or visit www.volkmannusa.com.*