Mill performance matched to the task

Throughput enhanced by optimising cooling and disc configuration

Various designs have been introduced to replace standard smooth discs in horizontal mills. The newly developed discs are available in both plain form and with additional bumps that increase agitation of the beads. Appropriate selection of these discs and a new cooling package increases output while reducing the necessary specific energy input.

Figure 1: Division of the space between two grinding discs into volumes of differing energy density [6]

Figure 2: Evolution of grinding disc geometry

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Agitator bead mills are used for the grinding of a wide variety of products in industries including foods, pharmaceuticals, agrochemicals, microelectronics, ceramics and fillers. Some of the key products manufactured with these machines are pigments, dyes, paints and printing inks.

Essentially, the comminution processes in these mills can be categorised as either true comminution or dispersion processes. With true comminution, fractures must be triggered in crystalline or amorphous particles in order to achieve a reduction in the particle size. However, sometimes small primary particles are already present in agglomerates or aggregates and are held together through binding forces of varying strength. Therefore, depending on the products to be ground, machines are required with which a varying energy density can be obtained. This has been successfully accomplished with the development of the new disc geometry for horizontal mills.

Theoretical principles of bead milling

Grinding in agitator bead mills is influenced by various operating parameters. Extensive investigations have shown that the essential factors are the specific energy input, the stress energy of the grinding media, the number of effective particle stresses and the dwell time of the particles in the mill.

For batch processes, the grinding energy for the product is calculated from the duration of grinding and the power input to the mill. The specific energy input is derived from the grinding energy relative to the ground product volume. For fully continuous processes, the specific energy input is determined by correlating the power input to the product mass flow or volume flow. Stehr [1] and Weit [2] have shown that the progress of comminution for each product is primarily determined by the specific energy input.

Further studies [3-6] have shown that a direct correlation exists between the stress energy of the grinding media, the number of effective impacts and the specific energy input required to achieve a specific result. Here the stress energy is understood as being the kinetic energy of the grinding media, which is subject to a more or less broad distribution depending on the design of the machine. This kinetic energy is determined primarily by the mass and speed of the grinding media. An effective impact event results if sufficient energy can be transferred to the product upon impact to trigger a particle fracture or to overcome the binding forces between the primary particles. Grinding media stress energies that are either too low or too high for the specific task can increase the amount of energy dissipation, producing unwanted heat.

How increased power density affects mill performance

Some mill manufacturers advertise ever higher power densities that can be achieved in agitator bead mills. This means that the power input obtainable is increased as grinding chamber volumes become ever smaller. The...
advantage is obvious – with such mills, greater production output can be achieved with smaller grinding volumes. However, one should keep in mind that there can be no reduction in installed motor power and hence the drive unit, the mechanical seal, the bearing and the entire machine stand. This means that the only initial savings result from the fact that the machine can be operated with a smaller amount of grinding media.

This trend only makes sense if large amounts of stress energy are required for comminution of the product or if care is taken that with the increase in power input more effective grinding media contact also takes place. Effective grinding media contact means that the kinetic energy of the grinding media at impact and the energy transferred to the stressed particles exceed the fracture energy or the binding energy so that comminution progresses.

However, if this energy, identified as grinding media stress energy, is greater, the excess amount is primarily converted to heat or, in addition to the heating of the product during the comminution process. The Netzsch “Cool Plus” package has been developed to provide optimum cooling for machines of up to 60 litres capacity.

Factors affecting power density in horizontal mills

Higher power input can be achieved through the rotational speed of the agitator shaft and primarily through the mill geometry and the geometry of the accelerating elements. Particularly high power densities can be realised in agitator bead mills with annular gap geometry with pegs or even a peg/counter-peg arrangement rather than discs.

Here, the grinding media are more intensively activated and accelerated by the pegs. At the same time, a considerably narrower grinding media speed distribution results from the annular gap geometry as compared to what are known as full-volume or disc agitator bead mills. The result is that, in a direct comparison of agitator bead mills with annular gap geometry and pegs to the conventional full-volume or disc agitator bead mill, the disc agitator bead mill with roughly twice the grinding chamber volume and the same grinding media fill level has the same power input at a comparable peripheral speed. A stress or accelerating element is understood as being a disc if it has a closed external contour with no sharp transitions, through which no activation element (such as a peg or other non-circular part) of any kind is formed.

Results at a glance

The design of horizontal bead mills should be optimised for the task to be carried out. A certain level of impact energy is required to provide effective grinding but very high impact energy levels will generate excessive heat.

Over the years, several different designs have been introduced to replace standard smooth discs in horizontal mills. Today, the newly developed discs are supplied in both plain form and with additional ‘bumps’ on the face that increase bead agitation. By changing between these two types of discs, mill performance can be optimised for the grinding of different pigments.

An optimised cooling system has also been introduced for the company’s horizontal mills. Changing the disc geometry and optimising cooling can greatly increase production rates while reducing the necessary specific energy input.

Energy distribution in disc agitator mills analysed

Stender [6] provides a very comprehensive description of the movement and energy density in disc agitator bead mills. For analysis, the space between two grinding discs is divided into four volumes which are characterised by different energy densities (see Figure 1).

In volume V1, the tangential speed of the grinding media increases from the centre (i.e. from the agitator shaft) to the outside. At the same time, the tangential speed of the fluid, and therefore of the grinding media as well, drops sharply from the agitator disc outwards in the axial direction. Due to this sharp drop in speed, grinding media impacts with large speed differentials are obtained in volume V1, especially in the axial direction, which results in the transfer of large amounts of stress energy. In volume V2, the tangential speed of the grinding media falls...
from values that almost correspond to the agitator disc peripheral speed at the outer edge of the agitator disc to almost zero at the grinding chamber wall. Therefore, large amounts of stress energy are also transferred to the product in volume V2.

Due to the greater distance from the agitator disc, the grinding media speeds are significantly lower in volume V3 than in V2, while in volume V4 there is no longer a clear shear rate in the axial or radial direction. The grinding media circulate at a certain tangential speed, but only minimal speed differences appear. Therefore, in volume V4 only grinding media contact with negligible stress energy occurs. Also, due to the centrifugal forces present, the concentration of grinding media in volume V4 is significantly reduced.

**Modified disc geometry increases efficiency**

The conventional geometry of the grinding disc is the centre-mounted solid disc. In recent decades, a wide variety of disc geometries with different outer contours and hole shapes or slots have been marketed (see Figure 2). With these discs eccentrically mounted on the agitator shaft, the movement of the grinding media was radically altered. In addition to the radial activation of the grinding media, impulses were now transferred to the grinding media in the axial direction as well. This led to an increase in the effectiveness and to an improvement in flow behaviour in the mill.

The company’s “LME” agitator bead mills were equipped with these eccentric discs and it quickly became apparent that, due to strong vibration, this arrangement would not be able to control up to a certain machine size. Therefore, disc geometry was developed in which three eccentric discs were effectively combined in one disc. The resulting agitator disc became known as the “Trinex” geometry and was the standard disc geometry for these horizontal disc mills for many years.

This idea was picked up by other mill manufacturers. For example, Premier developed a grinding disc shape with four corners. With this shape, the drawback of the “Trinex” geometry, a smaller average disc diameter compared to a concentric round disc, could be counteracted without giving up the additional activation of the grinding media in the axial direction.

Following the acquisition of Premier by Netzsch in 2010, this disc geometry was transferred to the company’s horizontal mills. In addition, a new concept was developed based on the disc shape. A further disc geometry was formed by special activation elements which are arranged on the front of the grinding disc.

The name of this new geometry is “Tetranex” for smooth discs without activation elements and “Tetranex Plus” for discs with activation elements. Due to the activation element on the front of the grinding discs, the grinding media in the space between two grinding discs are activated by additional axial impulses. A significantly higher energy density is achieved with greater energy utilisation.

There are two practical configuration options for these grinding discs. Combining smooth discs with those having activation elements facilitates energy-intensive grinding with high power input.

**Faster production with improved quality**

Packaging inks are frequently produced with an agitator bead mill. A field test was run with a customer (see Table 1) in which different operating parameters were varied in order to optimise the production of a red packaging ink.

After the first test, the grinding system of the machine was converted to discs with the optimised cooling package. The existing grinding media were replaced with more wear-resistant beads with a higher grinding media density. Due to the improved thermal conductivity...
of the grinding chamber lining, it was possible to lower the product outlet temperature despite the increased power input. As a result, by increasing the amount of grinding media and the peripheral speed from 10.8 m/s to 12 m/s the power input was increased even more in further tests without exceeding the required maximum temperature of 60 °C. With additional optimisation of the dwell time distribution by combining a pre-grinding pass at a higher product throughput rate and a second pass at a lower product throughput rate, a product was created that showed significantly better quality characteristics (sheen, covering power and transparency) than the standard. The production output increased from 60 kg/h to 103 kg/h (approximately 72 %), with a simultaneous reduction in the required specific energy of more than 40 % from 351 kWh/t to 204 kWh/t of packaging ink. (An overview of these results is presented in Figure 4.)

Optimisation package with benefits guaranteed

Similar results from tests with different products confirm this experience. Therefore, the company offers existing customers with an agitator bead mill a special optimisation package for paint and printing ink. This optimisation package includes:

» The newly developed disc grinding system optimised to the application for higher power input and greater production output.

» Optimised cooling package, available for models up to the “LME 60” to guarantee lower product temperatures even for the highest grinding capacity (highest energy input).

Reference grinding can be carried out with the existing grinding system, upgrading of the machine, followed by a performance test run. Process analysis with the company’s specialists is provided to discover additional optimisation potential (such as predispersion or modified machine parameters) and consultation on optimum choice of grinding media.

The conversion of existing machines leads to a marked increase in the production output, of more than 50 % in most cases. Therefore, for every customer who purchases the full optimisation package, the company offers to return the machine to its original state at no net cost if the increase in output is less than 30 %.

Optimisation increases output, reduces energy

Grinding of products such as paints and coatings in what are known as full-volume or agitator bead mills is an established technology. The development of a new disc geometry successfully combines the advantage of full-volume mills (large quantity of grinding media) with the benefit of peg mills (narrow grinding media speed distribution). This sets a new trend in increasing the power input with a simultaneous increase in the number of effective impacts in the mill. The benefit for all users, increasing the production output while lowering the specific energy requirement, reduces production costs considerably.

Figure 4: Increase in production output with simultaneous reduction of specific energy input required for the manufacture of a red packaging ink

This has been shown in extensive field tests with real products. With the full optimisation package, the production output of existing customer plants was increased in some cases by more than 70 %. In the process, the required specific energy input was reduced in some cases by more than 50 %.

REFERENCES