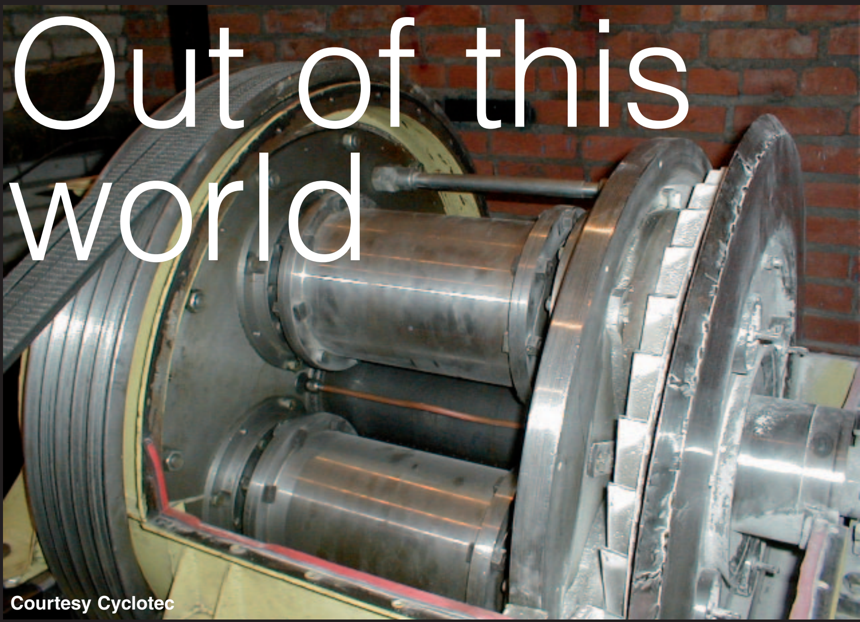
Out of this world



Courtesy Cyclotec

Finally realised after 120 years on the drawing board, the Planetary Centrifugal Mill™ (PCM™) claims to be one of the most efficient grinding technologies in the world today

BASED ON A US patent from 1886, the Planetary Centrifugal Mill™ (PCM™) developed by Cyclotec, is thought to be one of the most cost effective methods for large scale production of ultra fine and sub-micron powders.

The mill operates on a similar principle to a ball mill, although in addition to rotation of the mill around a longitudinal axis, the drums also rotate around an axis according to the motion of transport – similar to the way in which planets rotate around the sun. Consequently, during the grinding process acceleration up to 300g can be achieved.

Accelerating benefits

Owing to this huge acceleration, materials undergo ultra fine grinding in a minimal volume, permitting an extremely compact footprint, and with incredible energy efficiency due to an energy density in the mill of more than 2,000 kW/m.^{3}

This high energy density also makes grinding very energy efficient. Indeed, the PCM mill is reported to consume half the energy compared to conventional grinding when grinding through 400 mesh. For example, a 20µ silica product can be achieved from F80 500µ (top size 1mm) at an energy consumption rate of less than 50kW/tonne.

Additionally it allows the mill to have an unmatched reduction ratio from 5mm feed to product size down to 20µ. Not only can this be achived within a matter of seconds, but also as a continuous process.

As well as operating with grinding media, the mill can also perform without grinding media, allowing an even lower power draw, and eliminating contamination. The feed size capability in this mode is up to 70mm, permitting drastic improvements in critical class limitation.

The mill also offers very low wear rates, as the size reduction of particles is achieved by attrition and not impaction, as the grinding media move within the mill as one body, so there is no impact of the grinding media on the drum walls or between the grinding media themselves. As a result, the feed enters the mill during revolutions and is milled among the grinding media or against the wall of the drum.

Furthermore, wear is moderate as although the grinding is performed at high acceleration, the linear speed within the mill is moderate at 8 m/s.

At such speeds, the mill does get very hot – a factor that has proved problematic in other planetary mill design attempts. However, excess heat is easily removed by water cooling, and by using the final product discharging from the mill as a heat exchanger – in this case the higher the capacity of the drum the lower the temperature inside the drum.

The mill also has an extremely compact footprint and a low weight (around 1.2 tonnes for a 1.5 t/h production capacity). It is also easy to maintain (a complete assembly and disassembly takes around 6 hours), and can be operated both in batch or continuous production in either wet or dry grinding mode.

Gaining control

In terms of mill control, the PCM is also quite unique in that owing to the set-up of the mill there are two extra parameters that can be adjusted to allow greater control of the grinding process – centrifugal speed and the ratio of angular speeds. Of these, the precisely computed ratio of angular speeds is the most important for the elimination of the critical speed limitation, at any centrifugal speed.

In a regular ball mill, if you increase the acceleration then you will get the feed clinging to the drum walls which subsequently does not get ground down. However, in a PCM material is prevented from clinging to the walls, as when the material is grounded the centre shaft rotates clockwise, whilst the drums rotate anti-clockwise. Consequently the motions balance each other out and there are no centrifugal forces to stick material to the sides.

Thus precise computation of balance of angular speeds, and optimally selected centrifugal load, allow grinding any material of any hardness with maximal efficiency.

Activating the benefits

A further benefit of the PCM is the ability to induce mechanical activation in the ground material. Knowledge of mechanical activation has been around since the 1960s when scientists studied the effects of very fine grinding of materials.

As the particles disintegrate and get smaller and the particles become closer to the elementary cell, drastic changes in the physical-chemical properties are observed. For example, some mechanically activated powders can have significantly lower sintering temperatures, and the process can also induce the formation of particles with a higher density. As a result, the material sintered from a mechanically activated powder would have higher density, hardness, and strength.

Mechanical treatment can also change the thermodynamic potentials of reagents and diminish the temperatures of the chemical reactions. This is because for many solid state reactions, the limiting stage is the diffusion of reagents in the solid state, a process that can be intensified during mechanical activation allowing much faster reaction times.

In addition, mechanically stimulated synthesis can be performed at temperatures up to 50 % lower than those in the conventional synthesis. For instance, one can encounter situations when conventional synthesis of a compound is impossible, for example, because of decomposition taking place. In these instances, mechanically stimulated synthesis can sometimes change the reaction temperature and can therefore make the synthesis possible. When necessary, mechanical stimulation can also induce decomposition.

Although the science is in its infancy the concept does present the possibility of carrying out reactions in the absence of solvent. Not only does this make processes simpler and more economical, but it is also ecologically advantageous.

There are many examples of where this may be highly advantageous within the minerals industry including:

- Silica – alumina and alumino-silicates can be activated to form valuable catalysts.
- Bauxite – bauxite can be activated by milling, allowing the easy extraction of $Al(OH)_3$ by concentrated NaOH solution at lower temperatures. This allows a purer $Al(OH)_3$ to be obtained
- Phosphates – phosphate can be amorphised under high mechanical impact, leading to a material than can be more easily attacked by the plant roots. This new fertilizer, tribophos, is cheaper than those obtained by treating the mineral with sulphuric or phosphoric acid.
- Concrete – instead of using sand and gravel in the concrete industry, activated ground silicate containing rock can be mixed with cement and water to form a very hard concrete called superconcrete

Technological development

Up until recently manufacturers have been unable to develop the technology on a large scale, although others have managed to manufacture the mills on a laboratory scale with operating loads of around 12 g. Attempts to increase the operating loads, have largely resulted in dramatically reduced running times before damage occurred to the planetary gear.

Some of the main problems encountered in these experiments included:

- The difficulty of designing a planetary gear which can operate at high loads and high speeds
- The complexity of design required to ensure the even and continuous feed and discharge of material
- Heat removal from the drum
- Provisions for dust removal

For the past 14 years, Cyclotec has been developing the PCM entirely from the drawing table to the semi industrial scale model with 1.5 t/h capacity and 20 litre milling volume which is in operation today. No lab-scale prototypes preceded it.

Unlike other attempts, the PCM is able to operate for thousands of hours without down time due to planetary gear malfunction. Testament to this is the mill's current operation, with Cyclotec providing milling services to local industries in the St Petersburg area. Materials already processed include silica sand for a paint filler, zircon oxide, silica carbide and glass.

The current mill was commissioned at the end of 2004, the mill has been successfully operated for a year. However, to take the technology further, to upscale the process, and to facilitate the technology worldwide, Cyclotec is currently looking for a strategic partner to work with them on the technology.

Aim high

Performing entirely as expected, with all the physical test results holding true to those predicted, the team is also confident that the model can also be easily scaled up – both because the mill operation has so far conformed with mathematical expectations, but also because in bench tests the planetary gear has withstood forces of up to 300g. This figure, which is ten times more than the mill currently operates at, would increase the production capacity of the mill to >50 t/h in ultrafine grinding mode.

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The PCM has been in operation for one year now toll grinding materials from local industries. Courtesy Cyclotec

Planetary gearing explained

Epicyclic gearing or planetary gearing is a gear system that consists of one or more outer gears, or planet gears, rotating about a central, or sun gear. Typically, the planet gears are mounted on a movable arm or carrier which itself may rotate relative to the sun gear. Epicyclic gearing systems may also incorporate the use of an outer ring gear or annulus, which meshes with the planet gears.

The gear ratio in an epicyclic gearing system is somewhat non-intuitive, particularly because there are several ways in which an input rotation can be converted into an output rotation. The three basic components of the epicyclic gear are:

- sun – the central gear
- planet carrier – holds one or more peripheral planet gears, of the same size, meshed with the sun gear
- annulus – An outer ring with inward-facing teeth that mesh with the planet gear or gears

In any epicyclic gearing system, one of these three basic components is held stationary; one of the two remaining components is an input, providing power to the system, while the last component is an output, receiving power from the system. The ratio of input rotation to output rotation is dependent upon the number of teeth in each gear, and upon which component is held stationary.