Performance of the Simoloyer®

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1.) Introduction

The Mechanical Alloying (MA) technique can be used to synthesize alloy powders with interesting properties. The technique, developed some 20 years ago, [1] can be described as a repeated deformation, fracture, and welding of powder particles by highly energetic ball collisions. [2] MA is important for creating materials with controlled microstructures and enables us to answer the demand for the high-performance materials of modern technologies. The various materials that can be prepared by MA are summarized in *table 1*.

Table 1: Applications of Mechanical Alloying

1.) Nanocrystalline Materials
2.) Amorphous Materials
3.) Oxide-dispersion-strengthened Alloys
4.) Iron and Oxide based Magnetic Materials
5.) Bearing Materials containing Solid Lubricants
6.) Wear-resistant Carbide- and Nitride-based Materials
7.) Nanocrystalline Ceramics

Today MA is used in different fields of research but just in a few industrial processes. Various technologies demand different types of MA equipment, depending on the required quantity of powder. Starting with a few grams, the shaker-mill may be the most suitable device; for needs in the range of kilograms, Simoloyer are used; and finally, modified drum-mills are used to prepare powder batches in the range of tons.

2.) Advantages of the Simoloyer

The most special device for High Energy Milling is the Horizontal Simoloyer. *Figure 01* shows a Zoz-Simoloyer model CM01 fitted with a cylindrical change grinding unit W01-2l having a capacity 2 liters. The cross section (*figure 02*) shows a change grinding unit W01-2lk, also of 2 liters capacity but having a biconical grinding space.

Figure 01: Simoloyer® CM01

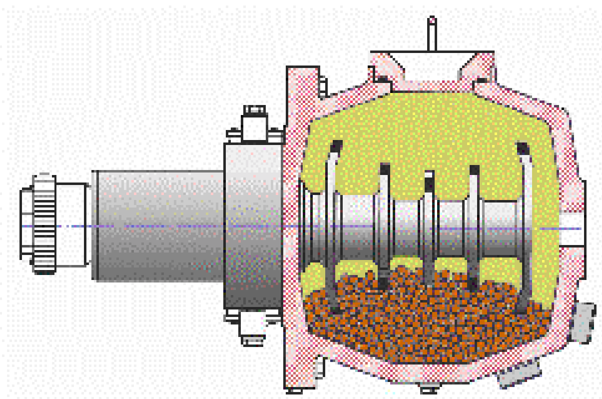

Figure 02: grinding unit WM-2lk, cross section

Typically, the CM01 Simoloyer is a rotary ball mill with a horizontally borne rotor, intended for dry-operation. Important characteristics (*figure 03, 04*) of this unit are the strong rotor with broad blades, the air-lock-connection, an adjustable pre-seal unit, an extension chamber, and the rotary seal. As in case of all horizontal systems, the effect of gravity on the milling media is overlaid by the impact of the rotor and, due to its strong design, the Simoloyer can be operated at a 2 up to 3 times higher rotational speed than conventional vertical attritors. Consequently the CM01 Simoloyer reaches a much higher kinetic energy impact. Further advantages of this Simoloyer are: (a) extremely high energy impact possible, (b) no dead zones due to gravity, (c) no different densities in the process, (d) charging and discharging under controlled atmosphere (vacuum or inert gas) by means of an air-lock.

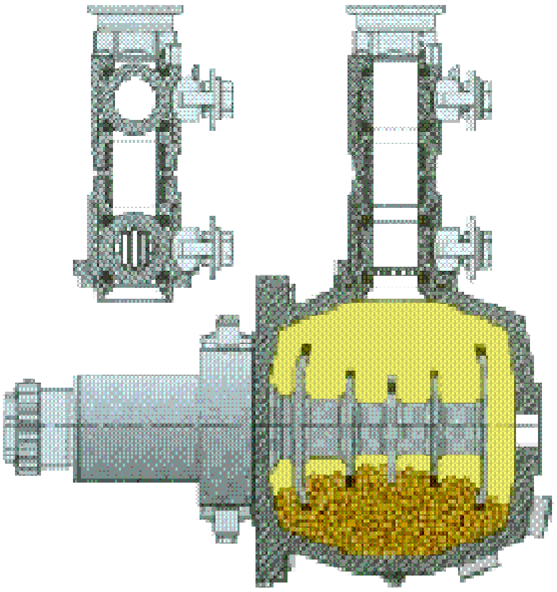

Figure 03: grinding unit, characteristics

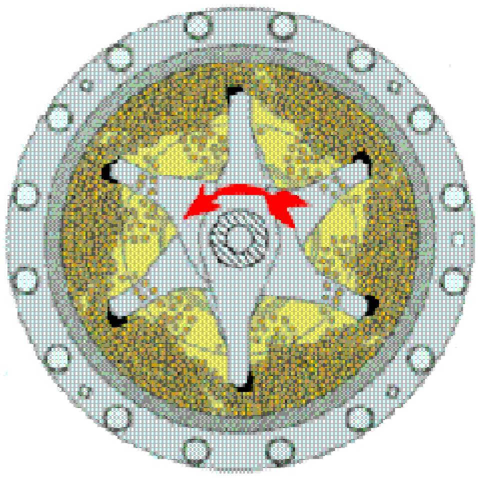

Figure 04: grinding unit, characteristics

3.) Analysis of the milling parameters in the horizontal Simoloyer®

Up to now, there has been no model available for the horizontal attrition process which would allow to calculate the milling parameters in order to optimize the microstructure of the powder. Therefore the reproducibility and the optimization of the milling parameters is today done by trial - and - error.

The present paper is a first attempt to desire a model for the milling process in the horizontal Simoloyer.

It has been shown by several scientists, that the primary event for the energy transfer to the processed powder is the collision itself (*figure 05*)[3][4]. This means that the most important parameter in the MA process is the kinetic energy of the impacts.

The kinetic energy is described by the well known formula:

$$W_{kin} = \frac{1}{2} m v^2 \qquad (1)$$

where m is the mass of the ball and v is the relative velocity of the balls.

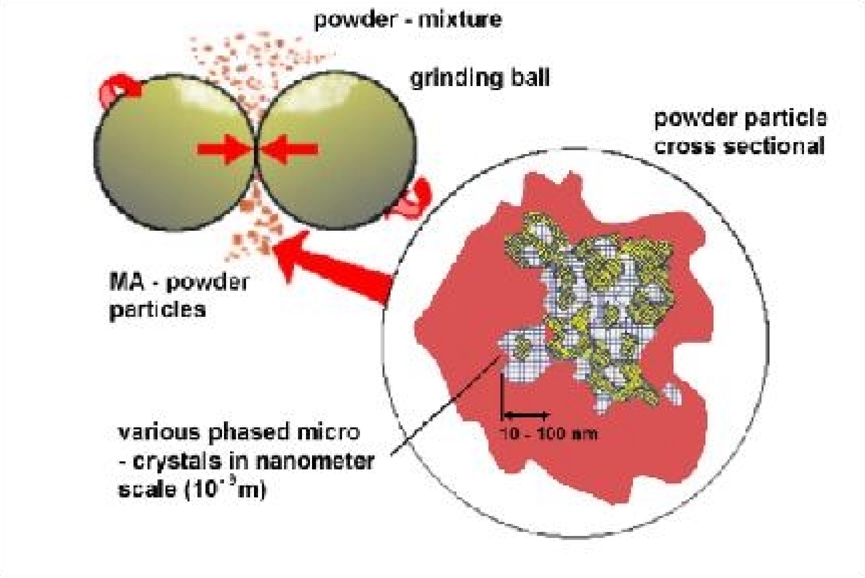

Figure 05: Schematic collision of balls (basic mechanism of MA)

Simoloyer allow a high velocity of grinding balls where the ball velocity is expressed in terms of the rotational speed of the rotor and an effective diameter for the center of gravity of a theoretical slide of the forced ball packet.

Figure 06 shows the simplified schematic cross section of the grinding chamber of the Simoloyer model CM01-2l. The main dimensions are:
a) Diameter of the vessel $\mathbf{d_v}$ = 146 mm, (b) Diameter of the rotor $\mathbf{d_r}$ = 116 mm, (c) Length of the vessel $\mathbf{l_v}$ = 135 mm, (d) Rotational speed (max) $\mathbf{n_r}$ = 1200 Rpm

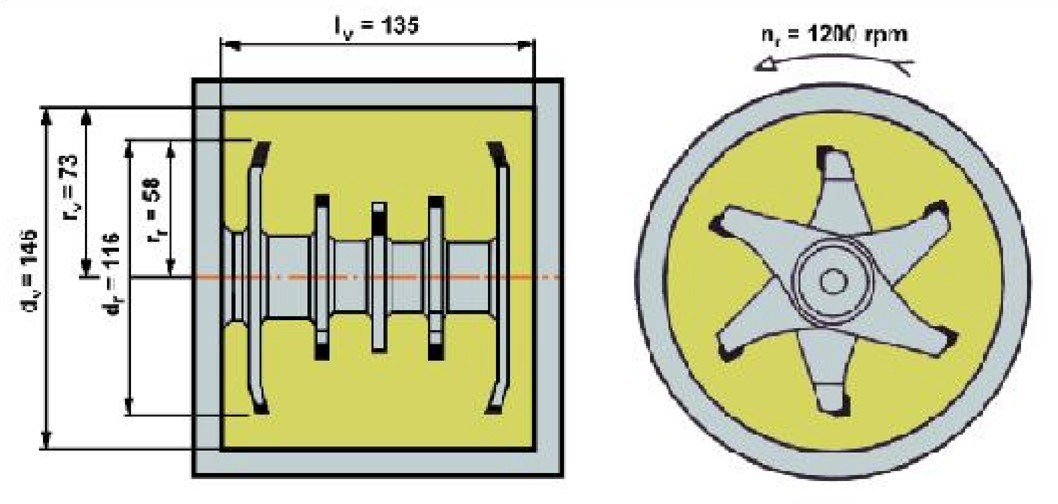

Figure 06: CM01, simplified cross section of the grinding unit W01-2l

In case of a uniform rotational speed, highest velocity will be transferred to the balls located near the end of the rotor blades. This is calculated by:

$$v_{b\max} = \pi \, n_r d_r \qquad (2)$$

For the case of the rotational speed of 1200 rpm, the result for the CM01 Simoloyer is:

$$v_{b\,\max} = \pi \quad 1200 \, \frac{1}{\min} \quad 0.116\,\mathrm{m} = 437.09 \, \frac{\mathrm{m}}{\min} = 7.28 \, \frac{\mathrm{m}}{\mathrm{s}}$$

This is the maximum velocity that is transferred by a 90° impact of the rotor blade onto a ball located near the end of the blade. This ball will attain this velocity for a short time. Following this collision, the ball will loose velocity by collisions with other balls.

To reach a similar ball velocity during free fall under vacuum (*figure 07*), the ball should be dropped from a height:

$$s = \frac{v_b^2}{2 g_e} = \frac{\left(7.28 \, \frac{m}{s}\right)^2}{2 \times 9.81 \, \frac{m}{s^2}} = 2.7\, m \qquad (3)$$

For MA in drum-mills, the angular velocity is adjusted to achieve the transition of cascade to cataract mode (*figure 08*).[5] In that case the free fall height is approx. 55 % of the diameter of the drum. Consequently the drum-mill diameter would need to be at least:

$$d_d = \frac{2.7 m}{0.55} = 4.9 m \qquad (4)$$

This simple calculation demonstrates one of the main advantages of the horizontal Simoloyer.

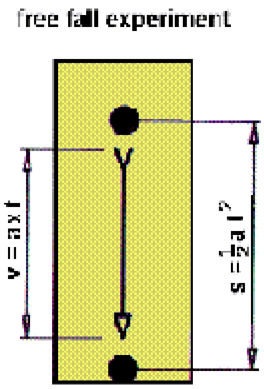

Figure 07: Free fall experiment

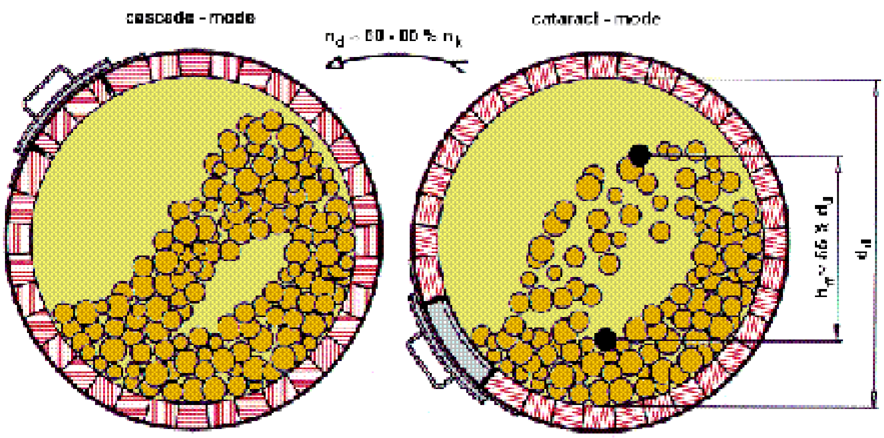

Figure 08: schematic cross section of a drum-mill

4.) Determination of the optimum ball size and filling ratio

In the Simoloyer, the free play or tolerance between the rotor and the inner vessel surface is d_v - d_r (*figure 09*). To avoid the blocking of the system, it is very important to obey the relation:

$$d_v - d_r \geq 5\, d_b \qquad (5)$$

As the kinetic energy is proportional to the mass, the balls have to be as big (heavy) as possible. As a matter of fact, the inner vessel surface and the balls are coated during almost any MA process. So the advice for the CM01 Simoloyer is:

$$d_v - d_r = 6\, d_b \qquad (6)$$

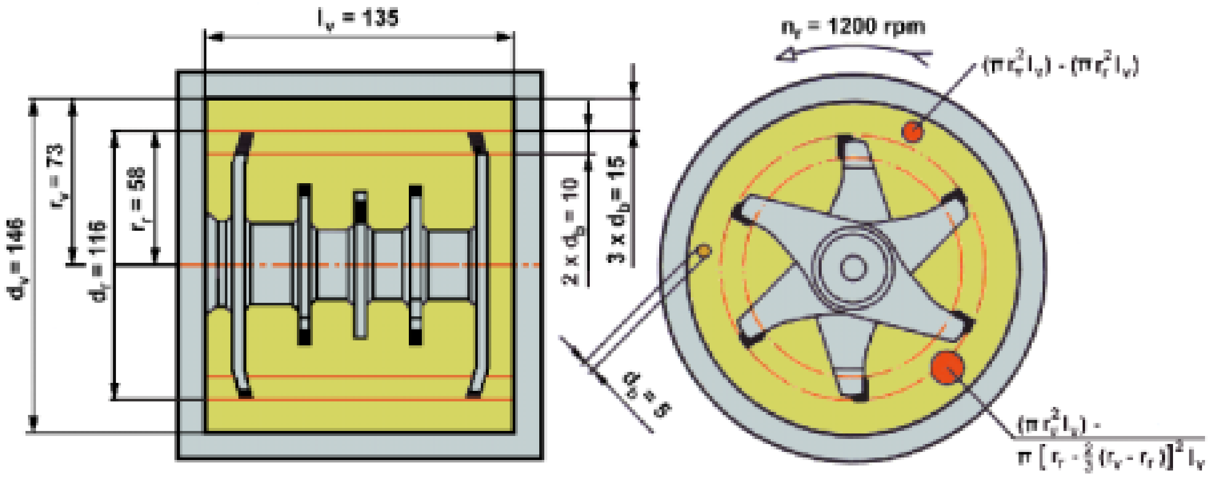

Figure 09: CM01, simplified cross section of the grinding unit W01-2l

Consequently for the present examination of Simoloyer CM01-2l, the optimum diameter of the grinding balls is 5 mm.

The vessel volume that needs to be filled up with balls in order to guarantee that all the balls will impact the rotor blades at the same time can be expressed by the hypothesis:

$$V_b \geq (\pi\, r_v^2\, l_v) - \pi\, [r_r - 2/3\, (r_v - r_r)]^2\, l_v \times \mathbf{k_d} \times \mathbf{v_b} \qquad (7)$$

where $\mathbf{k_d}$ represents the density of the ball packet when accelerated, and $\mathbf{v_b}$ is the velocity of the balls. It shall be noticed that if the velocity goes to zero, the chamber has to be filled up to 100 % in order to obey Eq (7).

To allow a high degree of free space for free movement of the balls and a high kinetic impact per collision, the milling container should not be filled more than necessary. Experience has shown that the best filling ratio is:

$$V_{exp} = (\pi\, r_v^2\, l_v) - (\pi\, r_r^2\, l_v) \qquad (8)$$

This is the volume between rotor and chamber circle of the Simoloyer (*figure 09*), which for the Simoloyer model CM01-2l is 0.83 dm^3. In order to reach this result, the product $\mathbf{k_d} \times \mathbf{v_b}$ in Eq (7) is taken as **0.65** . This result is valid for all known Simoloyer sizes.
Consequently, the formula for the volume of grinding balls becomes:

$$V_b = (\pi\, r_v^2\, l_v) - \pi\, [r_r - 2/3\, (r_v - r_r)]^2\, l_v \times 0.65 \qquad (9)$$

For the grinding chamber of the CM01-2l Simoloyer, the result is:

$$V_b = [\pi\, (0.73 dm)^2\, 1.35\, dm] - \pi\, [0.58\, dm - (0.73\, dm - 0.58\, dm)]^2\, 1.35\, dm \times 0.65$$

$$\mathbf{V_b = 0.83\, dm^3} \qquad (10)$$

For the case of the 5 mm steel-balls, 0.83 dm^3 correspond to a mass of 4 kg.
Following the hypothesis again, 4 kg of grinding media are accelerated to the velocity:

$$v_{BP} = v_{bmax} \times k_s \qquad (11)$$

The factor k_s describes the sliding effect and is expected to be not higher than 0.5

5.) Control and Data Acquisition System: description of the MALTOZ® program

For a better understanding of the milling process in the horizontal Simoloyer, it is necessary to record or if possible to control the process parameters and the process data. In particular the dependency of temperature, time, velocity and energy impact is of major importance.
The computer program MALTOZ has especially been created to control and supervise the Simoloyer, the process and its documentation (milling history) [6].
MALTOZ is working with Interbus-S and is available for all Simoloyer-sizes from 0.25 up to 400 liters grinding-chamber-capacity.
The remarkable features of these new generation of **CM-Simoloyer** are: (a) operation on ordinary PC, (b) all variations of speed and time with ramps and breakpoints etc., (c) full documentation concerning speed, time, temperature and power, (d) controllable process temperature, (e) safety functions human and hardware.

MALTOZ measures the total energy consumption of the Simoloyer by the formula:

$$P_{tot} = 1.73 \times U_C \times I_C \times \cos\varphi \times \eta \qquad (13)$$

where 1.73 is the root of 3 and represents the phase difference of 120° of three-phase current, and where U_C is the voltage applied and I_C the current of the converter. The constant $\cos\varphi$ describes the phase difference of I_C and U_C and η represents the efficiency of the motor.

Figure 10 shows the graphic of a trial with 4 kg steel-balls. The power consumption is 665 W at a rotational speed of 1200 rpm. The same trial with an empty chamber shows a power consumption of zero at the same time and in the same scale. This is certainly not correct and refers to a problem of measuring the power with high precision in that stage - and has to be improved. The power difference between the filled and the empty chamber trials is in this case is 665 W and represents the power consumption by the milling media.

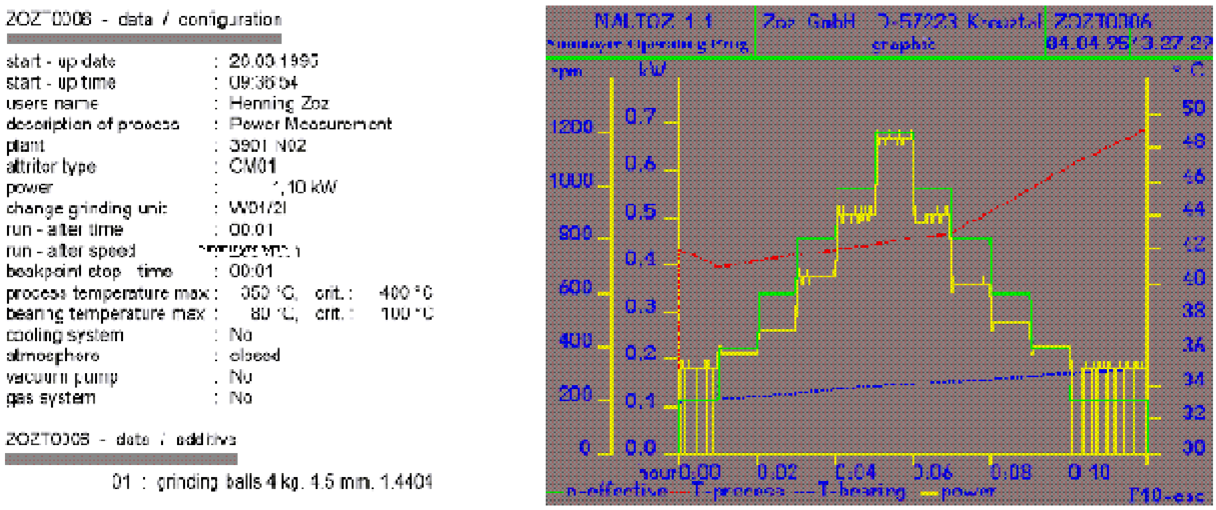

Figure 10: Result of Maltoz® in real testing

6.) Conclusions

The important advantages of horizontal Simoloyer have been explained. On the one hand caused by the horizontal borne rotor, on the other hand due to a strong design as well as available air-lock systems.
These horizontal Simoloyer can fill a gap between the shaker mills and huge drum-mills.
It has been shown how to determine the optimum ball size and filling ratio and what record and control is possible by means of the Simoloyer operating program MALTOZ.

From the point of view of the manufacturer, there is a strong demand for further improvements of MALTOZ, certainly the fitting of at least one representative Simoloyer with a torque meter and a kinetic study of the ball collisions by high speed cinematography.
And there is further work to be done on the model.

7.) References

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