Shaping Technologies
Norbert Nies, SMS Meer

principles and basics
compaction process
shape/compaction methods
applications
Process of Uniaxial Powder Compaction

From Powder to the Green Part
Powder - Process Flow

Challenging Areas

From the Top Main Powder Supply

To the Cavity

Compaction Process

Filling

Hopper

Intermediate Hopper

Hose

Filling Plate

Filling Shoe

Programmable CNC Axis with Linear Encoder
- Fast
- precise

principles and basics
Two Basic Methods of Powder Filling

Volumetric and Gravimetric Filling Method

**Volumetric Filling**
by gravity, most system in use

**Gravimetric Filling**
by pre weighing the powder mass

Diagram showing:
- Filling Cavity
- Filling Plate
- Punches
- Filling Shoe
- Powder Dosing
- Powder Weighing
Different Techniques for Die Filling

Basic Procedures

- **Volumetric Filling**
  - 1: Initial filling
  - 2: Final filling

- **Underfill**
  - 1: Initial filling
  - 2: Final filling

- **Overfill**
  - 1: Initial filling
  - 2: Final filling

- **Suction Filling**
  - 1: Initial filling
  - 2: Final filling

- **Shadow fill**
  - 1: Initial filling
  - 2: Final filling

- **Contour fill**
  - 1: Initial filling
  - 2: Final filling

- **Profile fill**
  - 1: Initial filling
  - 2: Final filling

**Principles and Basics**
General Requirements for Die Filling

Requirements for best filling conditions

- Press allows highest repetition accuracy stroke by stroke for position of all punches and die
- Filling system allows highest repetition accuracy stroke by stroke for powder flow equality from the top main powder supply to the cavity filling shoe speed profile and position for- and backwards the powder quantity the distribution of the powder in the cavity
- Well skilled and process trained operators for best part related adjustments of the filling system
- Optimised tool design, geometry, temperature, magnetism and quality
- Good Environmental Stability (Temperature, Humidity)
- Constant Powder Quality (Corn size, Additives, Flowing Behaviour)
Simple kind of uniaxial compaction

one sided compaction

fill position

press position

one sided compaction
die fixed
core rod fix or floating

principles and basics
Counter pressue principle of uniaxial compaction

double sided compaction

fill position

press position

upper punch

compact

die

lower punch

core rod

double sided compaction
die fixed
core rod preferably floating
Withdrawal principle of uniaxial compaction

Double sided compaction

die machine actuated
core rod preferably floating
Proportional Ratio during Compaction Process

\[
\frac{H_1 \text{ filling}}{H_2 \text{ filling}} = \frac{H_1 \text{ compacted}}{H_2 \text{ compacted}} = \frac{V_1}{V_2}
\]
Stress reaction of the powder during compaction

The influence of the stress during compaction between the powder and the die (e.g. using one side compaction).

\[
\bar{\tau} = \frac{1}{h} \int_0^h \tau(x) \, dx
\]

\[
\bar{\tau}_D = \frac{F_D}{\pi Dh}
\]

\[
\bar{\tau}_{CR} = \frac{F_{CR}}{\pi d_h}
\]
Influences during compaction

The influence of the stress during compaction and the related friction between the part and the die and punches pending to the dimensions.
Technical problems during ejection

Ejection force relative to the punch travel

- Due to the residual radial forces, considerable force has to be applied to eject the parts from the die.

- The residual radial forces must be minimised in order to avoid large ejection forces and hence problems with the die.
Technical problems during ejection

The state of tool and lubricant to the ejection force

- Excessive die wear or inadequate lubrication can cause fretting of the part on the die wall.
- A higher ejection force is required and ejection is not uniform (squeaking)
Part take off principles

Ejection function

filling  compaction  ejection
Part take off principles

Withdrawal function

- filling
- compaction
- withdrawal
Compaction Process
CNC Hydraulic Powder Press with CPA

1. Upper ram: top punch level
2. Hydr. ram: top punch-level
3. Hydr. ram: top punch level
4. Lower docking unit
5. Upper docking unit
6. Filler
7. Lower ram: lower punch level
8. Hydr. ram: lower punch level
9. Hydr. ram: lower punch level
10. Hydr. ram: lower punch level
11. Lower docking unit
12. Die ram

Compaction process
Controlled Punch Adapter
**Controlled Punch Adapter Technology**

**Example CNC lose loop control**

### Features and Advantages

- **Utilization of servo-hydraulic drive technology**
  for getting higher press forces by very high positioning accuracy

- **No mechanical fixed stop in press position**
  no mechanical tuning
  no spring-back-effect

- **Compensation of punch compression**
  Even density distribution
  also at complex parts geometry

- **Extreme big flexibility**
  of all punch movements inside the press cycle

- **Reduction of set-up time**
  by pre-calculation of the punch movements of the press-cycle

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CPA Technology Process

Operation Cycle of the Powder Press in 8 key steps

1. Filling
2. Under-filling
3. Start powder transfer
4. Transfer position
5. Compacting
6. Force reduction
7. Withdrawal
8. Release

compaction process
In the filling position, a volume of powder corresponding to the volume of the part to be produced has been supplied via a filling system. The die and the individual punches are already positioned relative to one another ready to move the powder after the filling is finished.

The underfill position ensures good closing between the upper and lower punch in order to avoid powder spillage.
Step 3
Powder Transfer

The powder transfer movement of the individual punches is the most important precondition for achieving a uniform or optimum density distribution. The start of powder transfer and the speed which should be in relation to the upper ram therefore allows the powder to be moved appropriately to the part geometry and the material to be moved from the fill condition to the transfer position without pressure being applied to the powder. Each punch moves individually according to the part design.

For some part geometries it could be very effective to use a second powder transfer movement. This could be carried out during filling i.e. when the filling shoe is over the cavity to create thin wall thicknesses, or after the first transfer movement to use that movement for precompaction in a relatively long section of the part in relation to the other sections.
Powder transfer

stroke [mm]

time [sec]

compaction process

6 5 4

6 5 4

4 5 6

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Step 4
Transfer Position

The transfer position shows the uncompacted part in relation to the compact as a function to the powder mix used. This condition could also be named the start of compaction.
In the main compaction phase, all the punch systems in use should be moved with appropriate timing and speed to the compacting position. It is of particular benefit here if these punch movements can be performed under continuous path control in relation to the upper ram which provides the reference value for the other axes. In view of the different sectional part heights, the resulting speeds must be controlled in such a way that all the systems reach the compacting position at the same time. This presupposes a controlled movement, particularly of the lower punches, under force up to the maximum compaction force but without the use of mechanical dead stops.

A brief standstill of all punch systems in compacting position offers enormous benefits for the subsequent relief phase and reduces the spring-back effects of the part itself.
CPA Press Method

Transfer position
Compacting position
Force reduction position

stroke [mm]

die

6 5 4

4 5 6

cd = compensation of deflection individually by each ram

No die move

cd6
cd5
cd4

compaction process

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Conventional Press Method

- **Transfer position**
- **Compacting position**
- **Competitor’s force reduction position**

<table>
<thead>
<tr>
<th>Competitor</th>
<th>´s force reduction position</th>
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<tbody>
<tr>
<td>Die move</td>
<td>(DM) cd4 &gt;cd5 &lt;cd6</td>
</tr>
<tr>
<td>cd= compensation of deflection by die lifting</td>
<td></td>
</tr>
<tr>
<td>d=deflection</td>
<td></td>
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</tbody>
</table>

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Step 6

Force Reduction

To optimally compensate the different punch deflections occurring during compacting, the rams can be moved on both sides, above and below the compacting position during force reduction when using a CPA. This becomes increasingly necessary if the length of the various levels or their respective surface areas are substantially different.

![Diagram showing force reduction process with compensation of deflection individually by each ram.](image)
Step 7 + 8
Withdrawal + Release

The withdrawal of the tools takes place after the relief phase, whereby the die and all the punches are moved back to a part removal position. This eliminates the necessity for ejection motions, which typically increase the risk of cracked parts.

This release position is also called the base or tool exchange position.
Visualization of Ram Position (mm) over Time (sec)

Active Cycle Diagram

<table>
<thead>
<tr>
<th>act. Val.</th>
<th>90.000 mm</th>
<th>180.000 mm</th>
<th>90.000 mm</th>
<th>2.600 mm</th>
<th>10.16 s</th>
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<tr>
<td>system</td>
<td>UR</td>
<td>F1</td>
<td>LR</td>
<td>AR7</td>
<td>—</td>
</tr>
<tr>
<td>scalefact</td>
<td>-500.0 mm</td>
<td>550.0 mm</td>
<td>170.0 mm</td>
<td>150.0 mm</td>
<td>20.0 s</td>
</tr>
<tr>
<td>offset</td>
<td>-550.0 mm</td>
<td>-180.0 mm</td>
<td>-190.0 mm</td>
<td>-145.0 mm</td>
<td>3.5 s</td>
</tr>
</tbody>
</table>

compaction process

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General Requirements for Compaction Process

Conditions for best results

Requirements for best compaction conditions

• Press allows highest repetition accuracy stroke by stroke through rigid press design cares for low vibrations, appropriate hydraulic power

• Adapter like Multi Platen with dead stop partly CNC controlled or Controlled Punch Adapter – means fully CNC controlled

• Proper tool design and manufacturing

• Powder Transfer without any pre compaction to achieve best even density distribution in each part section

• Compaction with speed proportional compaction motion according PM rule punches and die CNC positioning according programmed speed and appropriate forces profile punch acting unlimited at bottom side and force measuring at compaction position thanks to the use of Controlled Punch Adapter

• Flexibility by multi axis in combination with free programmable use

• Well skilled and process trained operators for best part related programming of the compaction system
Multiple lower punches

Calculations of filling heights for each punch is a must to achieve even density distribution.
Steped die - core rod

It is necessary to move the die or core rod to achieve the neutral zone in the middle of the step.
Conical die – core rod

It is necessary to move the die or core rod to achieve the neutral zone in the middle of the step.
The use of profiled die platen and punches needs to modify the fill shoe itself.
Split die compaction

Split dies are used for parts which make a normal release of the part impossible, as the upper die moves up together with the upper punch.
Undercut

Compaction of cross holes

Undercut parts with holes are a special application, whereby punches are used radial.

**Attention:** Geometry must be conical.
Undercut parts with circumferential grooves are possible only with the use of counter compaction method.
Undercuts – side and top view
Multiple upper and lower punches use are state of the art as of today.

Cycle calculations (fill- transfer- compaction-position) is a must to achieve even density distribution.
Change of Demands on the PM Parts

15,000 kN  
7.2 g/cm³  
Higher press forces and more punch level due to shape requirements

10,000 kN  
7.1 g/cm³  
Punch shape does not meet opposite side

5,000 kN  
7.0 g/cm³  
Unsymmetrical CNC part, thin walls, one transfer ram for top section only

3500 kN  
6.9 g/cm³  
Symmetrical Conventional Part
Multi-level Compacts

Start powder transfer
Transfer position
Compacting
Force reduction
Withdrawal
Release

Multi-level Compacts

applications

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Helical Gear Technology

Borg Warner

Stackpole
Split Die Technology
Double fill and compaction process

Schematic with composite material

Filling 1  1. Pre compaction  Filling 2  2. Pre compaction  Final Compaction

applications
Oilpump gear made with composite material
Synchro ring made with composite material