Quality Management and Quality Control in the Powder Injection Moulding Process

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The powder injection moulding process is widely used to produce high precision structural parts of very high complexity in shape. The variety of materials ranges from ceramics and hard metals to stainless steels and low alloyed steels. As a near net shape process the entire process is very complex and needs the full attention of all the people incorporated. The early design activities are influencing the quality of the final product as well as the tool design and fabrication, the selection of raw material and binder system, and all single production steps and the secondary operations. For that, a well designed quality management and control system is necessary to control the powder injection moulding process in all the details. Such a system should incorporate a carefully organized systematic Failure Mode and Effect Analysis (FMEA). The combination of a high performance process monitoring system with the extensive application of statistical procedures creates the basis for a Statistical Process Control (SPC) system that meets all the requirements to produce multi-functional structural parts of high complexity in shape and of high performance materials. The paper will discuss such a quality management and control system in detail.
1. Introduction
2. What is possible
3. Principle problems
4. How to realize improvements with respect to technical characteristics and economy?
5. Design of a Quality Management system
6. Closing remarks
Metal / Powder Injection Molding is the combination of design features of plastic injection molded parts with the properties of high performance metals, hard metals or ceramics in a (near)-net-shape process.

Source: Schunk Sintermetalltechnik GmbH

Characteristics of the Process
1. Introduction
2. What is possible
3. Principle problems
4. How to realize improvements with respect to technical characteristics and economy?
5. Design of a Quality Management system
6. Closing remarks
Clamping device for a breaking system (3 MIM parts)

Functions
- Guiding
- Adjusting
- Clamping
- Connecting

Source: Schunk Sintermetalltechnik GmbH
Reduction of production steps

- Production of a forged and drilled bronze head
- Production of a steel tube
- Production of a spike
- Elimination of a bracing operation
Static Mixer

Elimination of electro-erosion machining

Simplification of Production

Source: Schunk Sintermetalltechnik GmbH
Actuator

Combination of complex shape and high strength steel

Realization of new Design Features

Source: Schunk Sintermetalltechnik GmbH
Mini gears for a tooth brush

Production quantity of 1.5 Mil. gears per year

Source: Schunk Sintermetalltechnik GmbH
Decorative chromium coated protection cap for a car looking system

Wide Range of Secondary Operations Available
Source: Schunk Sintermetalltechnik GmbH
Lever for a sun roof
Substitute for Precision Casting

Substitution of Existing Processes for Economic Reasons
Source: Schunk Sintermetalltechnik GmbH
Carbonyl Iron Powder

Pure Iron Carbon Steel with 0.6 % C

Micro-Structure Engineering – Development of Pure Iron Carbon Steel
Micro-Structure Engineering – Development of 100 Cr 6 Bearing Steel

Carbonyl Iron Powder

Chromium Carbide Powder

100 Cr 6 Bearing Steel As Sintered
Inert Gas Atomized
Stellite 6 Powder

Stellite 6 wear resistant steel

Micro-Structure Engineering – Development of Stellite 6 Wear Resistant Steel
Effect of Heat Treatment on Fe 2.5%Ni 0.6%C Steel
Forging, Die Casting PM (Die Pressing)

Metal / Powder Injection Molding (MIM / PIM)

Machining

Precision Casting

Complexity of Geometry

Competition of Processes
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Material Engineering

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Metal
Hard Metal-
Ceramic-

Powder

~ 60 vol-%

Organic Binder

~ 40 vol-%

Mixing
Homogenizing and
Granulating

Shaping using
Injection Molding

Removal of Binder

Sintering

Secondary
Operations

Complex Structural Parts
Ready to Use

Process Schematic
Shell-like arranged porosity due to sheer-induced separation processes in the feedstock during mold filling
Shrinkage hole due to sheer-induced separation processes in the feedstock during mold filling

(Visualization by means of micro-focus X-raying)

Typical Defects
Material Specification: AISI 316L

Plastic Elongation [%]

Round Robin Tests (Working Group MIM, Germany 1997)
1. Introduction
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Visualization of Process Optimization by means of Statistical Process Control Procedures
Comparison of Different De-binding and Sintering Conditions
1. Introduction
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Quality Control ↔ Quality Management

Quality control means: To find errors.
Quality management means: To avoid errors!

From the economic point of view
avoiding errors has the priority

What is the Focus of Quality Management?
Cost of Quality Control and Lack of Quality
Schedule of Defect Generation and Defect Detection

Source: Deutsche Gesellschaft für Qualität
You need a strategy for your system!

→ Organization + Documentation

→ Manufacturing + Control Resources

→ Personnel + Training

A Quality Management system should be regarded as a tool for a never ending improvement of the Metal / Powder Injection Molding Process
The Nature of a Quality Management System
Development of a Quality Management System for the MIM/PIM Process

1. Definition of Quality
2. Description of the Product and the Process
3. Process Analysis
   - FMEA, 6 Sigma ...
   - Prototype Production
4. Revised Product and Process Description
5. Results from Quality Control Activities
6. Start Production
8. Process Instructions
9. Working Instructions
10. Inspection of the Quality Management System by means of:
    - Internal Audits
    - External Accredited Certification Authority e.g. in accordance to EN ISO 9001 - 2000
    - Customers

Customers

Start Production

Results from Quality Control Activities

Revised Product and Process Description

Process Analysis
   - FMEA, 6 Sigma ...
   - Prototype Production

Description of the Product and the Process

Definition of Quality
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<tbody>
<tr>
<td>In-correct dimension</td>
<td>7</td>
<td>Wrong feedstock composition</td>
<td>Defective scale</td>
<td>Preventive calibration</td>
<td>4</td>
<td>Density measurement of feedstock</td>
<td>3</td>
<td>84</td>
<td></td>
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<tr>
<td>In-correct dimension</td>
<td></td>
<td>Wrong sintering</td>
<td>Furnace setting</td>
<td>Training of operator</td>
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<td>Comparison of furnace setting with process documentation</td>
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<td>Checklist (working instruction)</td>
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Risk Priority Number

\[
\text{RPZ} = B \times A \times E
\]

Risk Priority Number (RPZ) = Bewertungszahl für die Rangordnung

B: Bewertungszahl für die Bedeutung
A: Bewertungszahl für die Auftretenswahrscheinlichkeit
E: Bewertungszahl für die Entwicklungswahrscheinlichkeit

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FMEA-Form according to Deutsche Gesellschaft für Qualität
### B – Impact, that means the effect on the customer

- **1**  hardly observable
- **2 to 3**  inconsiderable or less disturbance
- **4 to 6**  low disturbance
- **7 to 8**  high impact, e.g. stop of production
- **9 to 10**  very high impact, e.g. risk for human beings

### A - Probability of occurrence of a defect

- **1**  unlikely,
- **2 to 3**  very low
- **4 to 6**  low
- **7 to 8**  medium
- **9 to 10**  high

### E – Probability of detection before shipment to the customer

- **1**  high
- **2 to 5**  medium
- **6 to 8**  low
- **9**  very low
- **10**  unlikely
The Risk Priority Number is calculated by multiplying the Weighting Factors

\[ \text{RPZ} = B \times A \times E \]

From the RPZ the priorities of actions are given by the following schema:
Design of a Quality Control Card

Internal Spezification

- Upper Specification (Mean plus 3σ)
- Upper Control Limit (Mean plus 2σ)
- Mean
- External Specification (tolerance band according to technical drawing)
- Lower Control Limit (Mean minus 2σ)
- Lower Specification (Mean minus 3σ)

Sample No.

Measurement
Improvement of Process Capability by means of Statistical Process Control (SPC)
Short Term Evaluation of Machine / Process Capability

Approval for Serial Production

Long Term Validation of Machine / Process Capability

Focus on
- Human Beings
- Machine
- Material
- Methods
- Environment

To be Subjected to a Process of Permanent Improvement

Machine Capability
Process oriented, but, min. 50 measurements
Result: $C_m$ and $C_{mk}$

Process Capability
Adequate long period of time under normal conditions of serial production to secure that all quality affecting circumstances can become effective.
Recommendation: min 125 single parts in 3 to 5 control samples
better is 20 Production days
Result: $C_p$ and $C_{pk}$
Pure Powder
Pre-Alloyed Powder
Powder Composition

Binder or
Components of
Binder

Recycled
Feedstock
(Gating Material)

Metering Out

Mixing and
Homogenization

Granulation

Feedstock
Characterization

Working Instructions
→ Handling
→ Storing Conditions

Properties
Production Data

Properties
Production Data

Documentation related to Feedstock Preparation
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The Basics of the MIM / PIM process are well understood.

- There are many different process routes available with respect to:
  - raw material selection
  - binder selection and binder composition
  - feedstock production
  - de-binding processes
  - sintering processes

- In the mean time a lot of measurement technologies have been developed to control the raw materials and feedstock characteristics in principle.

- Also the basics of the two-phase-flow-mechanics are available.

- The electronically controlled injection molding machines allow highly sophisticated control of the molding process.

- There are also highly sophisticated furnace systems available to control the de-binding and sintering processes.

- But nevertheless, very small scattering in the very complex system of a huge number of independent parameters have in special situations dramatic effects on the result of the entire MIM / PIM process and are causing big problems with respect to the quality of the product.

Closing Remarks
- the MIM / PIM process as an entire process is still very young and has its secrets.
- The interdependencies between the single, at the first glance independent process parameter are not very clear and cannot be described precisely enough to make MIM / PIM a fully automated process.
- MIM / PIM still needs highly experienced operators to make the process successful.
- A well-designed Statistical Process Control system combined with an excellent Quality Management system is necessary to produce multi-functional, complex shaped structural parts of high performance materials in high quantities in an economic way utilizing the Metal / Powder Injection Molding Process.
Economic Comparison of Different Processes - ideal Conditions and comparable Capacities (especially quality issues are not regarded)