LSR Molding Process Optimization Using High Speed Data Acquisition and Design Of Experiments

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Presentation Overview

- Factors Contributing to Making a Good Part
- Types of Process Monitoring Data - *Discrete vs. Continuous*
- Incorporating High Speed Data Acquisition and Cavity Pressure Monitoring Techniques - *Methods and Benefits*
- Understanding High Speed Data Acquisition Curves in LSR Molding
- LSR Machine and Cavity Pressure Curve Examples
- Design of Experiments with Kistler Data Acquisition
- Summary and Follow-up Activities
Four Factors that Contribute to Making a Good Part

Material

Tooling

Processing

Part Design
Types of Process Monitoring

Level 1 - Discrete Single Point Data (SPC)
• Provides Specific Value During Cycle – Peak Injection Pressure, Packing Pressure, Screw Cushion, Shot Size, Injection Time, Peak Cavity Pressure, Injection Velocity, Mold Temperature, Cycle Time, Dosage Time

Level 2 - Continuous High Speed Data
• Maximizes Process Information - Pressure Traces, Velocity Curves, Cycle Integrals
• Simultaneous Monitoring and Control - Verifies Correct Set-Points and Machine Controller Feedback
• Trouble Shooting - Helps Identify Machine Fluctuations Slow Switchover, Controller Tuning, Transfer Point
## Example Level 1 - SPC Type Data

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### Protocol cycle counter

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**A Snapshot During The Cycle**
Example Level 2 - Continuous High Speed Data

A Movie Over the Entire Cycle
Incorporating Process Monitoring into a LSR Molding Environment

Tool Qualification & Initial Start-Up
Level 2 Data

- Process Capability Studies (P-PAP)
- Process Optimization (DOE)
- Establishing Upper & Lower Spec Limits
- Tooling Design and Capability
- Material Verification

Manufacturing & Production
Level 1 Data

- Machine Status
- Process Dynamics
- Production Quantities
- Material Usage
- Scrap Rates
- Machine Scheduling

Trouble Shooting & Machine/Mold Setups
Level 2 Data

- Process Variation
- Equipment Wear
- Equip. Malfunctions
- Incorrect Process Setup
- Material Viscosity Shifts
- Machine Calibration
Traditional Methods To Solve Processing Problems

• Rely on processing experience

• **Start changing processing conditions** – *Injection Speeds, Mold Temperatures, Transfer Position, Pack Pressure, Cure Time*

• Call material supplier

• Call machine supplier

• Call mold maker

• **Ignore the problem(s)** - *Hope the problem goes away on its own*

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**High Speed Process Monitoring Allows You To Look Deeper Into The Molding Cycle**
High Speed Process Monitoring

Cavity Pressure/Temp Sensor

4 Channel Single Wire Connector

4 Channel Thermocouple Amplifier

CoMo Injection

Computer
Where Do You Measure

MAJOR MONITORING POINTS

- Injection Pressure
- Screw Position & Screw Velocity
- Barrel Feed Pressure
- Injection Start Trigger
- Cavity Pressure and Temperature
- From hydraulic power unit
Use of High Speed Data Acquisition using DOE
Inj. Pressure During Fill:
- Material Viscosity
- Gate Design
- Controller Tuning
- Drive Unit

Inj. Pressure at Transfer:
- Proper Switchover
- Pressure Limited
- Controller Response and Tuning

Cavity Pressure:
- Effects of Pack and Holding Pressures
- Proper Mold Shut-Offs
- Stability of Clamping Unit

Cavity Pressure:
- Transfer Point – Drop in Cavity Pressure

Pressure During Dosing:
- Constant Feeding
- Uniform Mixing

Cavity Pressure:
- Cavity Pressure Continues to Increase Until Mold Opens
Cavity and Injection Pressure with Screw Position

View
Prod. Order: GEA-2016015
Batch: DOE Midpoint
Batch Status: terminated
Mould: MT-108-02
Device: BH - CoMo Inj.

Cycle Time: 04/28/2016 18:12:51
Bad: 5
Good: 0

The channel entry has been corrected.

Start of Injection
Switchover to Hold
Mold Open
End of Hold

1: 0-5000 psi Cavity 2
7: 0-22500 psi Injection Pressure
8: 0-4 in Screw Position

Cycles: 1-11
Step: 1
Cha: 1,7-8
**Screw Position and Barrel Pressure**

- **Start of Injection**
- **End of Hold**
- **Screw Recovery**

Cycle Time: **04/28/2016 18:12:51**

- **Bad:** 5
- **Good:** 0

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6: 0-500 psi Barrell Feed Pressure
8: 0-4 in Screw Position

Cycles: 1-11
Step: 1
Cha: 6,8
Cycle Time: 04/28/2016 18:12:51 Bad: 5 Good: 0

1: 0-5000 psi Cavity 2
2: 0-5000 psi Cavity 4
5: 0-375 °F Cavity 2
6: 0-500 psi Barrel Feed Pressure
7: 0-22500 psi Injection Pressure
8: 0-4 in Screw Position

Cycles: 1-11
• Machine data curves overlaid
Overlays of Kistler Data Curves

- Machine and sensor data curves overlaid
Overlays of Kistler Data Curves

- Machine data curves overlaid
Overlays of Kistler Data Curves

Machine and sensor data curves overlaid
Part – Dishwasher Silicone Gasket


Process Parameters Measured – Screw Pressure, Screw Position, Barrel Feed Pressure, Cavity Pressure, Cavity Temperature

Gate Location:
• Center Gate
• Open Nozzle

Cavity Pressure and Temperature Sensor:
• Kistler 2.5mm Transducer
Part – Dishwasher Silicone Gasket


Process Parameters Measured – Screw Pressure, Screw Position, Barrel Feed Pressure, Cavity Pressure, Cavity Temperature
Design Of Experiments Setup

- 2-level Factorial Design
- 7 Factors
- 16 Runs
- Resolution IV
- 1 Centerpoint per block, 1 Replicate
- Total of 20 Runs
- 20 Samples per run
- Response Variables: Part Weight and Pressure Integrals
- Achieve constant part characteristics on every cycle
Design Of Experiments Setup

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Observations: Run 14 has a higher mold temp (340°F), slower fill time (1.3 sec), slower screw RPM (100), Lower barrel feed pressure (200psi).
Design Of Experiments Results

- Part Weight response was not significant, not enough resolution
- Pressure integrals showed significance
- Back Pressure while dosing showed influence for most repeatable cavity pressures

### Pareto Chart of the Standardized Effects

(response is Entire Pressure Curve, $\alpha = 0.05$)

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Factor Name:
- A Mold Temperature
- B Water Temperature
- C Fill Time
- D Back Pressure
- E Screw Recovery
- F Manifold Fed Pressure
- G Barrel Fed Pressure
For consistent pressure integrals among cavities:

- High Mold Temperature – 340 F
- Low Water Temperature – 65 F
- High Back Pressure – 300 psi

Main Effects Plot for Entire Pressure Curve
Fitted Means

All displayed terms are in the model.
Interpreting DOE Results

- Don’t take all DOE results as fact
- Good scoping tool
- Compare full and short part data to determine other factors
  - Vents getting flashed?
  - Hold pressure is equalizing cavities?
• Looking to the future:
  • Set relationship between customer CTQs and pressure integrals using correlation graphs and trend line equations
  • Establish robust process that achieves low cavity pressure variability
  • Run long-term stability study over multiple production runs (2-3 months, multiple drum kits of material)
Learning and Next Steps

- Move feed throat sensor
- Cavity pressure in a different location
- Varying lots of material stability
- Molding machine repeatability
- LSR Mixing and Pumping systems
- Stability with different injection unit
QUESTIONS ???

Special Thanks: