Improvement of hydraulic control quality for deep drawing presses through retrofit

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Outline & Introduction

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Introduction
- retrofit for presses every 10-15 years (electrical)
- some machines have hydraulic closed loop control system (die cushions (DC), ram cushions, hydraulic ram)
  - most machine manufactures use “of the rack” control system
  - special applications need special engineered solutions
- approach by TRsystems is a tailored control solution

Source: Drive Automotive Industries of America Inc.
### Tasks and Machines

<table>
<thead>
<tr>
<th>Arisa S-4-1600-470-230 LDE</th>
<th>MW ZE2100.45.2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>mechanical transfer press with Link-Drive engine</td>
<td>hydraulic tryout press with MultiCurve-technology</td>
</tr>
<tr>
<td>10 separate hydraulic die cushions</td>
<td>4 separate ram cylinders</td>
</tr>
<tr>
<td>2 servo valves per cushion</td>
<td>accumulator drive for forming stroke</td>
</tr>
<tr>
<td>3-chamber cylinder for every cushion</td>
<td>8 separate pressure cylinders for die cushion</td>
</tr>
</tbody>
</table>

#### Arisa S-4-1600-470-230 LDE
- **Year of manufacture**: 2005
- **Ram (force, stroke)**: 16,000 kN, 600 mm
- **Stroke speed**: 8 – 30 1/min.
- **Cushion (force, stroke)**: 600 kN, 200 mm

#### MW ZE2100.45.2.2
- **Year of manufacture**: 2006
- **Ram (force, stroke)**: 21,000 kN, 1500 mm
- **Speed (pressing, rapid down)**: 500 mm/s, 350 mm/s
- **Cushion (force, stroke)**: 6,000 kN, 350 mm
**Tasks and Machines**

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**Task for the retrofit**
- electrical retrofit of all 10 cushions
- hydraulic remains untouched
- closed loop control for
  - DC pressure and positioning function

**Before retrofit**
- heavy pressure overshoots and permanent oscillations
- no consistent component quality

**Task for the retrofit**
- electrical retrofit of whole machine
- new servo valves for all DC pressure cyl.
- closed loop control for
  - DC pressure and positioning function
  - ram pressure, velocity and parallelism function

**Before retrofit**
- no constant DC forces, esp. for higher die speeds
- fluctuations within ram’s velocity control
Ram velocity control

- trajectory should look like trajectory of a mechanical press

DC pressure control

<table>
<thead>
<tr>
<th>Force [kN]</th>
<th>1250 kN</th>
<th>2000 kN</th>
<th>3150 kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>1.3</td>
<td>1.5</td>
<td>1.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>

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acceleration distance
ram position [mm]
time [s]
top stop
rapid down
rapid up velocity
down
up
lifting velocity
die closed
closing
stroke
die closed
forming
ram velocity [mm/s]
return
lifting off
top stop
brake distance
lifting distance
bottom stop
acceleration
return
lifting

die closed
closing
stroke
die closed
forming
ram velocity [mm/s]
return
lifting off
top stop
brake distance
lifting distance
bottom stop
acceleration
return
lifting

DC pressure control

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Solution

Introduction

Solution

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Hardware

- existing control system replaced by Beckhoff IPC
- communication between S7 (840D) and Beckhoff via Profibus DP/DP
- 1 IPC controls all 10 die cushions
- EtherCAT I/O-modules with 16 bit resolution for analogue inputs and outputs

Hardware

- existing Beckhoff control system renewed
- new servo valves for DC pressure function (from 40 Hz to 50 Hz frequency)
- EtherCAT I/O-modules
- new motion sensors for ram's parallelism and velocity control

- 125 µs cycle time
- real-time capable
Solution

Software

- real-time extension Beckhoff TwinCAT (PLC, visualization and closed loop control)
- control algorithms are written in C++ and executed in ring 0 (kernel mode)
- control algorithms include
  - cam gear, trajectory generation, pressure-/position-/velocity-/parallelism-control…

DC pressure control

- PI-controller (10% of sum signal) and model based feed forward control (90% of sum signal)
- feed forward control is implemented as a 3-dimensionl valve characteristic
Solution

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Ram velocity control
- trajectory generation (5th order, jolt-free)
- velocity control consists of PI-controller and model based feed forward control
- feed forward control was optimized via implementing valve’s opening profile (servo cartridge Rexroth 2WRCE)

Ram parallelism control
- 4 position signal (every cylinder has its own sensor)
- position differences (tilting) are converted in tilting moments around x- and y-axis
- tilting moments are converted in resulting forces at cylinder center
- target value is 0.0 kN in order to eliminate tilting
- no interference between position-/velocity control and parallelism control
Results

DC pressure control
- before retrofit

Ram velocity control
- before retrofit

- after retrofit

- after retrofit
Results

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DC pressure control

- before retrofit

- after retrofit
Ram parallelism control

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Ram cylinder front-left
Ram cylinder rear-left
Ram cylinder front-right
Ram cylinder rear-right

Y
X

-B
+B

1.700 mm
3.800 mm

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8

0 20 40 60 80 100 120 140 160 180

ram position [mm]

tilting +B ram
tilting -B ram
tilting +B cushion
tilting -B cushion

0 20 40 60 80 100 120 140 160 180

ram position [mm]

tilting +A ram
tilting -A ram
tilting +A cushion
tilting -A cushion

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Conclusion

- retrofit has led to enormous enhancement of closed loop control quality
- quality improvement achieved by changes in hardware
  - new servo valves
  - fast and real-time control systems
- model based control algorithms led to new level of stability
- consistent component quality ensured

Outlook

- self-optimizing and self-adjusting control algorithms
  - reducing commissioning time
  - condition monitoring
  - compensation of wear
- using of faster IPCs and servo valves

Research project

adaptive control