# Hydraulic Systems for Die Cushions

## Technical information

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System solutions

Rexroth has established itself as the specialist in the automation of forming machines and develops industry-specific drive and control systems in close partnership with machine manufacturers. The range of products extends from individual components and modules to a wide range of drive systems.

One example is Rexroth's die cushion technology. The necessary know-how for project planning and implementation has been pooled in our application centers for decades. All of the necessary drive components, such as cylinders, power units, valve control manifold blocks including digital closed-loop controls, are offered from a single source. Furthermore, the very latest facilities are available for calculations and simulations in order to meet customer-specific requirements.

Together with the local sales organization, the application center translates the customers' wishes into drive solutions. Here, Rexroth relies on tried and tested solutions of top quality. This gives the systems a long service life. In addition, new developments can be implemented, for example the energy-saving die cushion. Old installations can also be modernized with the help of our solutions.

Die cushion technology

The requirements to be met by presses in the execution of deep-drawing processes change for technological and economic reasons. The use of new materials that are difficult to form, for example high-tensile sheet steel, and the forming of complex geometrical shapes require highly precise process controls. One example of such processes is the manufacture of bodywork parts. Besides new materials and complex geometry, other requirements must also be met here, for example flexible processes in order to achieve shorter product cycles and tool changing times.

Rexroth solves these press technology-related problems with its hydraulic die cushions. In highly productive mechanical presses, they reduce the slide impact on the workpiece or optimally build up the drawing force over the entire drawing stroke. This means that the material flow is controlled during forming, thus allowing the manufacture of complex geometrical forms without tears or creases in the workpiece. The pre-acceleration of the die cushion unit further improves the process, e.g. longer tool service life, less surface damage to the tool and lower machine noise levels.

With the help of Rexroth technology, machine manufacturers can reduce cycle times and increase the service life of the tools.

Die cushions may be used in mechanical as well as in hydraulic individual presses. Individual presses can in turn be components of a press line.

Here, blanks are automatically processed in the course of several processing stages.
Press lines

A press line usually consists of four to six individual presses with their various tools for drawing, cutting, punching etc. Normally, the lead press has the greatest pressing force and is equipped with a die cushion. It must carry out the greatest forming work.

As a rule, the downstream presses are smaller.

They are responsible for the subsequent processing of the blank (cutting, punching, folding, ...). The blank to be processed is transported between the individual presses by feeder, robot or crossbar systems. One variation of feeding raw material to the lead press is from a coil.

Components for the lead press:

1. Press crown: power unit, control manifold block (for hydraulic ram drive, not shown above)
2. Die cushion modules, further Rexroth systems are the ejector, parallelism control, electronics in the control cabinet, etc. (not shown here)
3. In this example: electromechanical slide drive (with Rexroth coupling/brake combination, overload protection)
   Alternatively: hydraulic slide drive (not shown)
4. Overload protection by Rexroth

Components for the press line:

5. Coil line with wound sheet metal coil, feeder, straightener and cutter
6. Additional systems for press automation: robots, feeders
Schematic representation of a press

A drawing press consists essentially of a press slide, to which the upper tool, here the female die, is attached. The press slide can be driven either mechanically or hydraulically.

A mechanical slide drive offers a high level of energy efficiency and high cycle rates; however, it has a rigidly prescribed motion sequence (the speed and pressing force cannot be adjusted).

Hydraulic slide drives, on the other hand, offer a very high level of flexibility with respect to motion and force control, but with higher energy consumption.

For the slide drive units, Rexroth also offers standardized hydraulic modules; for further information please refer to RE 63141.

The lower tool, here the punch, is connected to the press frame. The blank holder is connected to the die cushion modules by means of pressure pins and the die cushion box. The blank holders thus are actively driven. Rexroth offers hydraulic die cushion modules with a high level of dynamic force and accurate force control. This is why these drive units are also used in mechanical presses.

There are also a large number of different press versions which will not be described in greater detail here, e.g. single or double-action presses.
During the drawing process, a drawing part is clamped between the upper tool and the blank holder and drawn over the lower tool. This makes the material flow into the die.

The die cushion drive unit builds up the blank holding force through the blank holders. Here the force must be controlled in an optimum way. Too little force leads to a tendency towards wrinkling of the drawn part. Excessive force, on the other hand, causes tears.

However, the die cushion also assumes other functions, such as pre-acceleration. This reduces the slide impact on the workpiece. The die cushion can also help to prevent the material from springing back or jumping when the slide is lifted. A certain height for the loading or removal of parts by a robot can also be set with the help of the die cushion drive unit.

Motion sequence of the die cushion

1. Beginning of die cushion pre-acceleration
2. Automatic, low-impact transition from position to force control
3. Pressure build-up for the required drawing force with several linear interpolated force and position support points.
4. Drawing process with force curve separately programmable over the drawing depth and for each cylinder module
5. Decompression at bottom dead center

Variant 1:
6. Return to the BDC of the die cushion to prevent the material from springing back
7. Move to pick-up position (parts removal)

Variant 2:
8. Closed upward movement
9. Starting position
The technology

The cylinder modules are the heart of the die cushion equipment. They consist of double-acting hydraulic cylinders, control manifold block, hydraulic accumulator and integrated position and pressure sensors. All active open and closed-loop control operations required to achieve the drawing function are carried out by the cylinder modules.

This compact, highly rigid hydraulic system prevents oscillation problems and guarantees highly dynamic control response.

All open and closed-loop controlled motion sequences for achieving the drawing function are implemented using Rexroth cylinder modules.

As early as at the planning stage, Rexroth can guarantee that customer-specific requirements will be met, provided these are technically feasible and are ordered as a system.

The system consists of:
- MAC8 (software and hardware)
- control manifold block
- high-response valves
- sensor technology
- cylinders

all of which are ideally adapted to match each other.

Rexroth can test the technical feasibility by means of simulations, see page 15.
Hydraulic solutions by Rexroth

Principle of the hydraulics for the die cushion drive
All cylinder modules of the drawing equipment are designed identically and fitted with the same components, which means advantages in spare parts storage. Each cylinder module is an independently functioning unit.

The required drawing force is provided by combining several modules. A higher-level control realizes the synchronization of the modules. We use basic control components, large numbers of which have already stood the test of time in machine tools for many years.

The conventional hydraulic drive of the die cushion consists of a high-pressure port 1. This is permanently connected on piston rod side 2 of the die cushion cylinder. The hydraulic fluid is fed in on the piston side 3 through the high-response control valve 4 as well as through redundant safety valves 5 and 6. This provides extra pressure to the rod side.

Such circuits help to provide a high level of dynamic power. The redundant safety valves comply with the European safety standard EN 693. In particular the hazardous upward movement is thus monitored.

Precise force control during the forming process and velocity control during pre-acceleration are achieved by high-response control valve 4.

The Rexroth electronics 7 close the control loop with the signals from pressure and position sensors and the actuating signals for the high-response control valve.
Hydraulic solutions by Rexroth

Principle of the energy-saving die cushion
The energy-saving die cushion patented by Rexroth combines a high-pressure and a low-pressure circuit. The low pressure circuit is enabled on the cylinder rod side during the drawing process, i.e. during the fast downward movement of the die cushion.

During the upward movement, the high pressure circuit is enabled on the rod side as well as on the piston side of the cylinder (regenerative circuit). Compared to standard hydraulic drives with only a high pressure circuit, up to 40% of the installed power can be saved using the energy-saving die cushion.
Hydraulic solutions by Rexroth

Safety of hydraulic die cushions
Safety standards, such as the European standard EN 693, are complied with by the Rexroth hydraulics. This includes electrical position monitoring of redundant valves.

Furthermore, depending on the safety standards of the various countries, the pressure vessels of the die cushion modules are certified as standard.

As an option, Rexroth offers its customers an acceptance test certificate B (3.1 B) in accordance with DIN 50 049 / EN 10 204 for the hydraulics supplied.

Press control manifold blocks
The following illustration shows examples of the implementation of hydraulic control manifold blocks for die cushion drives. All active open and closed-loop operations for achieving drawing functions (pre-acceleration, drawing force control, return at bottom dead center or controlled upstroke with pick-up position) are implemented by the cylinder modules. Pipes and hoses are only for supplying pressure or serve as tank lines. All cylinder modules of the drawing equipment are identical and equipped with standard components (advantages in spare parts storage). Each control manifold block is an independently functioning unit. The required drawing force is provided by combining several modules. The electronic control realizes the synchronization of the modules.
Hydraulic solutions by Rexroth

For high-end applications Rexroth offers standardized manifold blocks in the sizes 40, 50 and 63. This function is already explained on page 7. The most important components are described in the illustration below:

1. Redundant safety control between A1 and A2
2. Pressure relief function against overpressure due to external force
3. Accumulator safety for pilot oil
4. High-response control valve
5. Accumulator safety and max. system pressure relief function
6. Accumulator for main drive
7. Accumulator for pilot oil
8. Accumulator discharge
Besides the high-end applications with the highly dynamic high-response control valves shown above, Rexroth also offers simple die cushion drive units with proportional pressure relief valves. The redundant position-monitored safety valves are also dispensable, provided the application permits this.

Rexroth offers the implementation of this simpler die cushion solution with the so-called J-module in sizes 25, 32 and 40.

For applications smaller than size 25 Rexroth offers vertical stacking assemblies with the following functions:

1. Directional control valve for traversing
2. Maximum pressure adjustment
3. Drawing force adjustment

This includes the following functions:

1. Directional control valve for traversing the cylinder, e.g. to the starting position TDC or for anti-cavitation at rod side during the actual drawing process (central valve position)
2. Pressure adjustment when drawing with proportional pressure relief valve (alternatively also with manually set pressure relief valve)
3. Pump protection and maximum pressure relief function
4. Safety against pressure intensification on the cylinder rod side
Hydraulic solutions by Rexroth

Valves
Fast high-response control valves of different sizes are available for controlling the die cushion cylinder. The valves are selected depending on the dynamic requirements. Valves for subplate mounting as well as cartridge valves are used.

The following table shows an extract of possible valves, for further sizes and valves please refer to the relevant data sheets.

<table>
<thead>
<tr>
<th>Valve designation</th>
<th>3WRC(E)</th>
<th>4WRSEH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Nominal flow at nominal pressure [l/min]</td>
<td>460 at 5 bar</td>
<td>720 at 5 bar</td>
</tr>
<tr>
<td>Max. flow [l/min]</td>
<td>1400</td>
<td>2200</td>
</tr>
<tr>
<td>Max. hysteresis</td>
<td>&lt; 0.2 %</td>
<td>&lt; 0.2 %</td>
</tr>
<tr>
<td>Frequency at 90° phase response</td>
<td>95 Hz (signal ± 25 %)</td>
<td>58 Hz (signal ± 25 %)</td>
</tr>
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For further information, see: RE 29135, RE 29136, RE 29137, RE 29069

* Switching time at 315 bar and 50 % stroke is 17 ms

<table>
<thead>
<tr>
<th>Valve designation</th>
<th>4WRDE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>10</td>
</tr>
<tr>
<td>Nominal flow at nominal pressure [l/min]</td>
<td>25; 50; 100 bei 10 bar</td>
</tr>
<tr>
<td>Max. flow [l/min]</td>
<td>170</td>
</tr>
<tr>
<td>Max. hysteresis</td>
<td>&lt; 0.2 %</td>
</tr>
<tr>
<td>Frequency at 90° phase response</td>
<td>100 Hz (signal ± 25 %)</td>
</tr>
</tbody>
</table>

For further information, see: RE 29093


Hydraulic solutions by Rexroth

Cylinders
For die cushion drive units, Rexroth offers special cylinders rated according to customers’ specifications, see illustration. For example, they allow velocities of 0 to 1500 mm/s to be realized. Jolt-free traversing, that is, without stick-slip effects, is possible at low velocities even in the range 0 to 10 mm/s. This is achieved by means of low-friction seals.

Power units
Whether only a few liters or tens of thousands of liters have to be put under pressure, Rexroth produces power units in accordance with the die cushion application, or further necessary press drives.

A distinction must be made between compact large-scale power units, in which all components are mounted on the fluid tank, and systems whose parts are separately connected by pipes to each other: Tanks, filter, cooler and heater stations, pump power units and control stands as well as valve tables and accumulator stands.

Together with the cylinder modules and high-response control valves, the die cushion drive can perform any press motion sequence. Depending on the customers’ specifications, the cylinders are selected together with the cylinder modules to suit the required die cushion forces. Optionally, adjustable die cushion forces, for example from 500 kN to 2000 kN per cylinder, are used.

Rectangular and cylindrical versions of tanks with capacities of up to 20,000 liters are standardized by Rexroth.

In addition, Rexroth can build and install special installations – with tanks of up to 60,000 liters and an output of 6,000 kW.

For hydraulic presses, power units with fluid volumes of up to 12,000 liters can be installed at the top of the press.
Die cushion control

The complex processes of die cushion controls require accurate interaction between Motion Control and hydraulic drive physics. Closed-loop control and coordination are carried out by Motion Control MAC8.

In numerous die cushion applications, the MAC8 has proved its reliability and flexibility in hydraulic drive open and closed loop control.

The optimum behavior of the electrohydraulic drive units is achieved through open and closed-loop control algorithms specifically adapted to the special characteristics of hydraulics.

Unlike controls that are purely adapted to electromechanical drives, the MAC8 takes account of the special physical characteristics of hydraulic drives in the firmware and in the software. It independently controls machine modules or entire machines, and also carries out PLC tasks. The Rexroth MAC8 uses open interfaces throughout and communicates with other controls via Profibus DP, Ethernet TCP/IP or Ethernet UDP. Additional peripherals or sensors are connected via a CAN bus. For visualization purposes it employs latest software such as OPC-Server or ActiveX, and utilizes Ethernet TCP/IP, RS232 as well as RS422 for data transmission. The MAC8 controls the movements almost independently of the cycle time of the higher-order machine control.

Examples such as die cushion control, parallelism control or slide control in presses show that with three basic components, the MAC8, valves with on-board electronics and cylinders, users can implement highly accurate automation sequences. The Rexroth MAC8 activates the valves in real time via voltage or current outputs, and closes the control loop by means of the position measuring system in the cylinder. The control supports incremental position measuring systems as well as the SSI interface and analog measuring systems. This guarantees extremely precise movements with easy configuration. The multi-axis control executes up to 32 NC programs parallel to each other. It supports simple closed loop controllers, state controllers, position-dependent braking, synchronization controllers as well as pressure/force controllers.

For many primary applications, frequently used motion control functions are pre-configured. This reduces the time and expense involved in engineering and commissioning significantly. As an option, the behavior of the machine can be adjusted very easily during operation in a visualization system specially tailored for end users - with the click of a mouse and entry of parameters.

The main application “Interlinked Axes” is optimized for the rapid implementation of die cushion functions. Here, the Motion Control uses a synchronization group for 2, 4, 6 or 8 axes (depending on the number of cylinders), a position/angle curve for calculating pre-acceleration, a speed/angle curve for command value feed forward of the force controller and force/distance curves for the required force curve of the die cushion cylinder.
Die cushion simulation

The simulation of the entire behavior of the drive unit is a valuable project planning aid in the engineering phase of a press installation, in order to see whether the selected components comply with the required performance data.

The physical properties of the components are stored as a mathematical model in a library in a suitable simulation program.

First a simulation model is built up from these library elements, analogous to the creation of the machine circuit diagram.

With the help of this simulation model, it is possible to carry out highly realistic examinations of the entire system or of individual components at an early stage of project planning, long before the prototype of a machine is built.

Furthermore, these examinations are especially necessary with press projects when the system properties of an installation type are already known and are to be enhanced. The components and parameters of the simulation model can then be examined for these specific requirements and adapted accordingly.

The following questions, which are absolutely essential in engineering, as well as other questions, can then be answered:

- Selection of pumps and accumulators:
  What does the ideal supply of pressure and volume look like?

- Selection of servo, proportional or high-response valve, type of controller and sensor:
  What drive and control structure guarantees compliance with the required parameters and tolerances?

- Oscillations of mechanical machine elements, distance from the supply unit to the press:
  To what extent does the mechanical structure of the machine influence its overall behavior?

Since the simulation model corresponds absolutely to the real installation, virtual commissioning of the drive components can also be effected on the computer.

The experience of a large number of simulations already carried out shows that the simulation results obtained correspond very exactly to the actual conditions in the installation.
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