Hydraulics
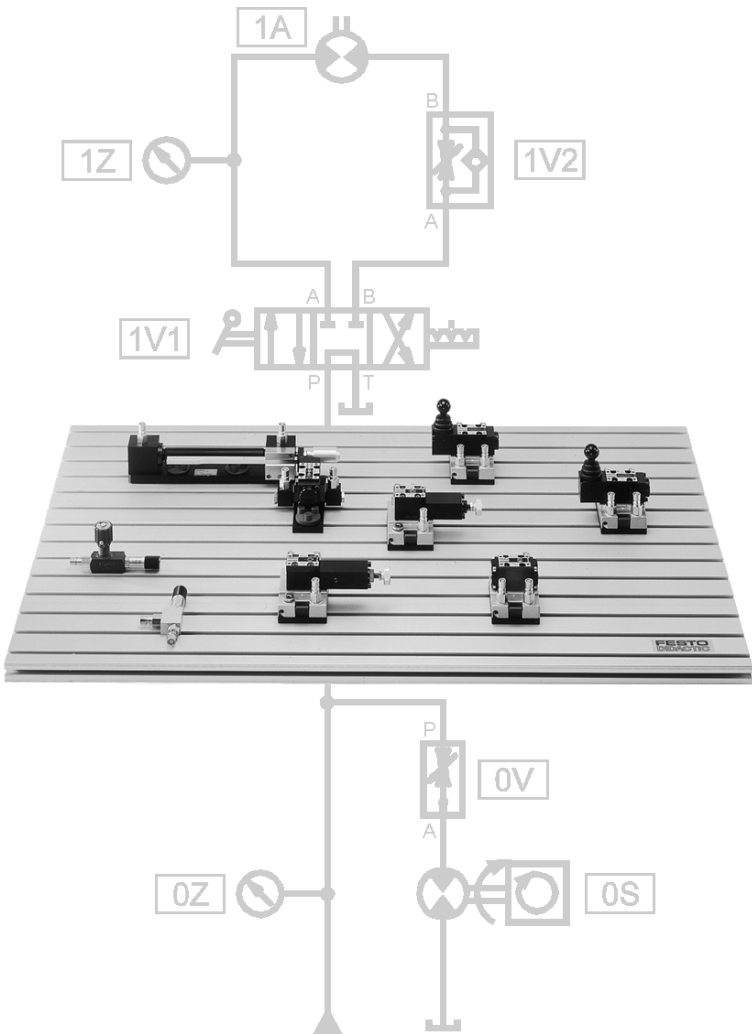
Workbook Advanced Level

Authorised applications and liability

The Learning System for Automation and Communication has been developed and prepared exclusively for training in the field of automation and communication. The training organization and / or trainee shall ensure that the safety precautions described in the accompanying Technical documentation are fully observed.

Festo Didactic hereby excludes any liability for injury to trainees, to the training organization and / or to third parties occurring as a result of the use or application of the station outside of a pure training situation, unless caused by premeditation or gross negligence on the part of Festo Didactic.

Preface

Festo Didactic's Learning System for Automation and Communications is designed to meet a number of different training and vocational requirements. The Festo Training Packages are structured accordingly:

■ Basic Packages provide fundamental knowledge of a wide range of technologies.

■ Technology Packages deal with important areas of open-loop and closed-loop control technology.

■ Function Packages explain the basic functions of automation systems.

■ Application Packages provide basic and further training closely oriented to everyday industrial practice.

Technology Packages deal with the technologies of pneumatics, electropneumatics, programmable logic controllers, automation with PCs, hydraulics, electrohydraulics, proportional hydraulics and application technology (handling).

Fig. 1:
Hydraulics 2000 –
i.e. mobile workstation

The modular structure of the Learning System permits applications to be assembled which go beyond the scope of the individual packages. It is possible, for example, to use PLCs to control pneumatic, hydraulic and electrical actuators.

All training packages have an identical structure:

- Hardware
- Courseware
- Software
- Courses

The hardware consists of industrial components and installations, adapted for didactic purposes.

The courseware is matched methodologically and didactically to the training hardware. The courseware comprises:

- Textbooks (with exercises and examples)
- Workbooks (with practical exercises, explanatory notes, solutions and data sheets)
- OHP transparencies and videos (to bring teaching to life)

Teaching and learning media are available in several languages. They have been designed for use in classroom teaching but can also be used for self-study purposes.

In the software field, computer-based training programs and programming software for programmable logic controllers are available.

Festo Didactic's range of products for basic and further training is completed by a comprehensive selection of courses matched to the contents of the technology packages.

Latest information about the technology package **TP502**.

New in Hydraulic 2000:

■ Industrial components on the profile plate.

■ Exercises with exercise sheets and solutions, leading questions.

■ Fostering of key qualifications:
Technical competence, personal competence and social competence
form professional competence.

■ Training of team skills, willingness to co-operate, willingness to learn,
independence and organisational skills.

Aim – **Professional competence**

Content

Part A	Course	Exercises
Part B	Fundamentals	Reference to the text book
Part C	Solutions	Function diagrams, circuits, descriptions of solutions and quipment lists
Part D	Appendix	Storage tray, mounting technology and data sheets

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Section B – Fundamentals

Section C – Solutions

Section D – Appendix

Introduction

This workbook forms part of Festo Didactic's Learning System for Automation and Communications. The Technology Package "Hydraulics", TP500, is designed to provide an introduction to the fundamentals of hydraulic control technology. This package comprises a basic level and an advanced level. The basic level package TP501 teaches basic knowledge of hydraulic control technology, while the advance level package TP502 builds on this.

The basic level hydraulic exercises are designed to be carried out with manual actuation. It is, however, also possible to use electrical actuation. The hydraulic components have been designed to provide the following:

- Easy handling

- Secure mounting

- Environmentally-friendly coupling system

- Compact component dimensions

- Authentic measuring methods

We recommend the following for the practical execution of the exercises:

- Hydraulic components: Equipment set TP501 and TP502

- One hydraulic power pack

- A number of hose lines

- A profile plate or a suitable laboratory trolley

- A measuring set with the appropriate sensors

_10_

This workbook provides knowledge of the physical interrelationships and the most important basic circuits in hydraulics. The exercises deal with the following:

■ Plotting of characteristics for individual components

■ Comparison of the use of different components

■ Assembly of various basic circuits

■ Use of basic hydraulics equations

The following technical equipment is required for safe operation of the components:

■ A hydraulic power pack providing an operating pressure of 60 bar and a flow rate of 2 l/min

■ An electrical power supply of 230V AC for the hydraulic power pack

■ A power supply unit with an output of 24V DC for solenoid-actuated valves

■ A Festo Didactic profile plate for mounting the components

The theoretical background is described in the "Hydraulics Basic Level" textbook TP501. Technical descriptions of the components used are given in the data sheets in Part D of this workbook.

Festo Didactic offers the following further training material for hydraulics:

■ Magnetic symbols

■ Hydraulics slide rule

■ Set of OHP transparencies

■ Transparent models

■ Interactive video

■ Symbol library

Notes on safety

Observe the following in the interests of your own safety:

- Exercise care when switching on the hydraulic power pack. Cylinders may advance unexpectedly!

- Do not exceed the maximum permissible operating pressure (see data sheets).

- Observe all general safety instructions (DIN 58126 and VDE 100).

Notes on operation

Always work in the following sequence when assembling a hydraulic circuit.

1. The hydraulic power pack and electrical power supply must be switched off during the assembly of the circuit.

2. All components must be securely fitted to the profile plate, i.e. securely snap-fitted or bolted down.

3. Check that all return lines are connected and all hose lines are securely fitted.

4. Switch on the electrical power supply first and then the hydraulic power pack.

5. Before dismantling the circuit, ensure that pressure in hydraulic components has been released:

> **Couplings must be connected and disconnected only under zero pressure!**

6. Switch off the hydraulic power pack first and then the electrical power supply.

Standard method of representation used in circuit diagrams

The hydraulic circuit diagrams are based on the following rules:

■ Clear representation avoiding crossovers as far as possible

■ Symbols conforming to DIN/ISO 1219 Part 1

■ Circuit diagrams with several loads are divided into control chains

■ Identification of components in accordance with DIN/ISO 1219 Part 2:

- Each control chain is assigned an ordinal number 1xx, 2xx, etc.

- The hydraulic power pack is control chain 0xx.

- Identification of components by letters:

    A – Power component

    B – Electrical sensors

    P – Pump

    S – Signal generator

    V – Valve

    Z – Other component

- The complete code for a component consists of

    – a digit for the control chain,

    – a letter for the component,

    – a digit for the consecutive numbering of components in accordance with the direction of flow in the control chain.

Example: 1V2 = Second valve in control chain 1.

Technical notes

Observe the following in order to ensure safe operation.

■ The hydraulic power pack PN 152962 incorporates an adjustable pressure relief valve. In the interests of safety, the pressure is limited to approx. 60 bar (6 MPa).

■ The maximum permissible pressure for all hydraulic components is 120 bar (12 MPa).

> **The operating pressure should not exceed 60 bar (6 MPa).**

■ In the case of double-acting cylinders, the pressure intensification effect may produce an increased pressure proportional to the area ratio of the cylinder. With an area ratio of 1:1.7 and an operating pressure of 60 bar (6 MPa), this increased pressure may be over 100 bar (10 MPa)!
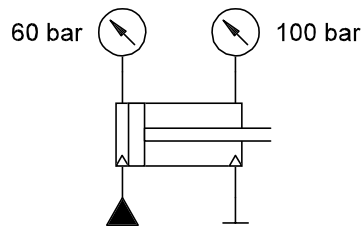

60 bar   100 bar

Fig. 2:
Pressure intensification

■ If connections are detached under pressure, the non-return valve in the coupling may cause pressure to become trapped in the valve or other component concerned. The pressure relieving device PN 152971 can be used to release this pressure. Exception: This is not possible in the case of hose lines and non-return valves.

■ All valves, other components and hose lines are fitted with self-closing quick-release couplings. This prevents the accidental spillage of hydraulic fluid. In the interests of simplicity, these couplings are not shown in circuit diagrams.
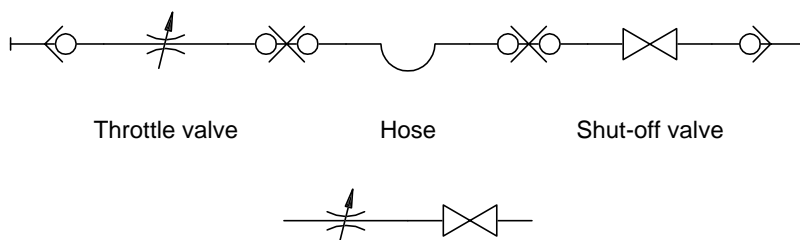

Throttle valve   Hose   Shut-off valve

Fig. 3:
Simplified drawing of
self-closing couplings

■ It is frequently necessary when assembling a control circuit to modify the given circuit diagram. Within the scope of the equipment set in this Training Package, the following alternative solutions are possible:

– Plugs can be used to change the function of directional control valves (Figs. 4 and 5).

– Directional control valves with different normal positions can be used (Fig. 6).

– Solenoid-actuated valves can be used in place of hand lever valves (Fig. 7).

Fig. 4:
Circuit diagram
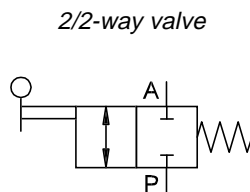
2/2-way valve *3/2-way valve*
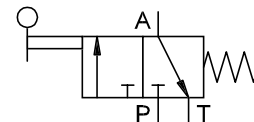
Fig. 5:
Practical assembly
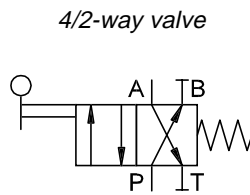
4/2-way valve *4/2-way valve*
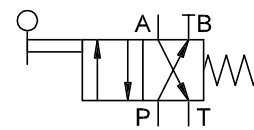
Fig. 6:
Directional control valves
with various
normal positions
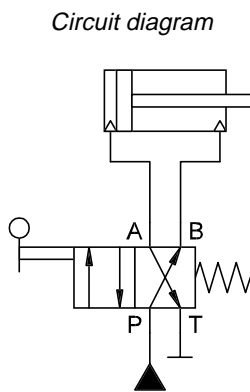
Circuit diagram *Practical assembly*
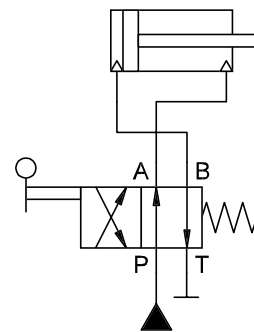
Fig. 7:
Solenoid-actuated
directional control valve
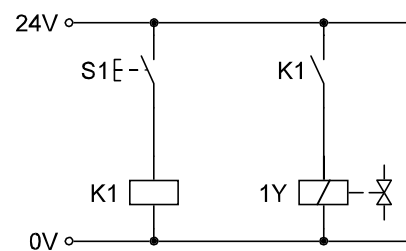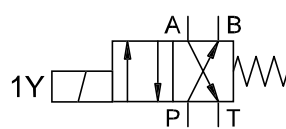
Flow rate sensor

The flow rate sensor consists of:

- A hydraulic motor, which converts the flow rate q into a rotary speed n.

- A tachogenerator, which produces a voltage V proportional to the rotary speed n.

- A universal display unit, which converts the flow rate q into l/min. The universal display should be set to sensor no. 3 for this purpose.
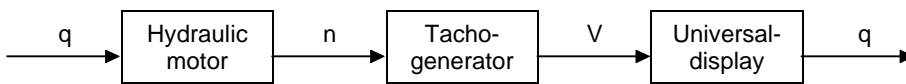
Fig. 8:
Block circuit diagram
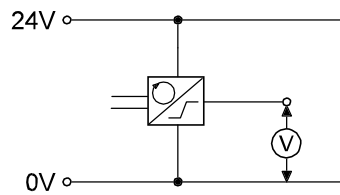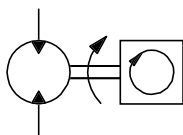
Fig. 9:
Circuit diagrams,
hydraulic and electrical
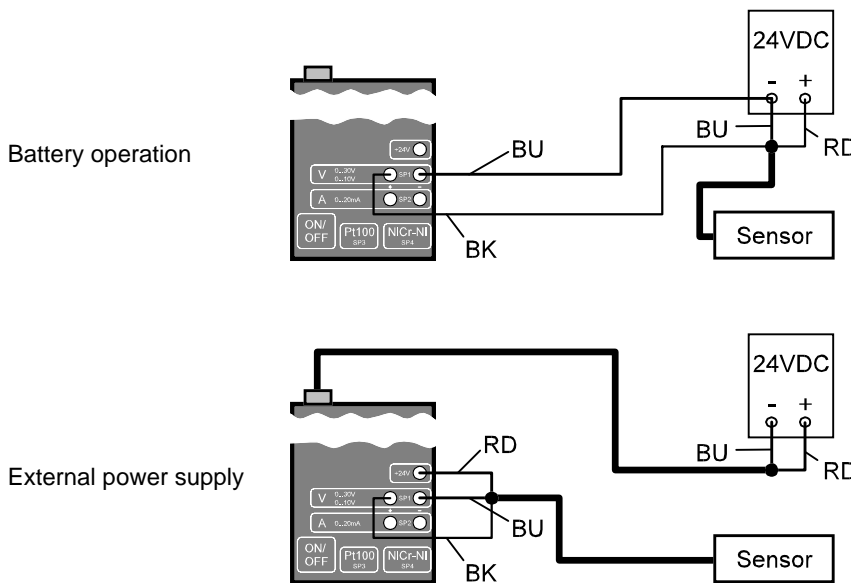
Fig. 10:
Connecting up the
universal display

Training contents of "Hydraulics, Advanced Level" TP502

- Uses of valves and other components

- Comparison of uses and functions of different valves and other components

- Measurement of variables such as pressure, flow rate and time

- Control of pressure and speed

- Calculations of area ratios, forces, speed, travel time, flow rate and energy consumption

- Basic physical principles of hydraulics

- Use of symbols in accordance with DIN/ISO 1219

- Understanding and drafting of circuit diagrams

- Drafting of displacement-step diagrams

- Assembly and commissioning of control circuits, including fault- finding

- Assessment of energy consumption

- Basic hydraulic circuits such as pressure sequence and dual pressure circuits, a bypass circuit to the pump, a differential circuit, circuits with flow control valves in the inlet, outlet and bypass, circuits with counter-holding, bypass circuits with a non-return valve, circuits to secure tractive loads, and motor and reservoir circuits.

List of training aims of exercises

Exercise	Training aims
1	Familiarisation with a hydraulic motor. Adjustment of direction and speed of rotation.
2	Familiarisation with a 2-way flow control valve. Use of a circuit with bypass.
3	Use of a flow divider for synchronous running of two cylinders.
4	Familiarisation with a rapid-traverse feed circuit.
5	Familiarisation with a differential circuit.
6	Use of a hydraulic accumulator as a pressure reservoir.
7	Familiarisation with a dual pressure circuit.
8	Familiarisation with a rectifier circuit.
9	Familiarisation with the use of 2-way flow control valves in inlet and outlet lines. Familiarisation with counter-holding.
10	Familiarisation with a sequence control with two cylinders. Familiarisation with a pressure sequence circuit.
11	Familiarisation with a safety circuit for a tractive load.
12	Familiarisation with the function and use of a pressure regulator.
13	Use of a hydraulic accumulator for a rapid-traverse circuit.
14	Familiarisation with a solenoid-actuated sequence control.

List of training aims

Hydraulic equipment set

Description	Order No.	Qty.
Pressure gauge	152841	3
Throttle valve	152842	1
One-way flow control valve	152843	1
Shut-off valve	152844	1
Non-return valve, opening pressure 1 bar	152845	1
Non-return valve, opening pressure 5 bar	152846	1
Branch tee	152847	7
Pressure relief valve	152848	1
Pressure relief valve, piloted	152849	1
Pressure regulator	152850	1
Flow control valve	152851	1
Non-return valve, piloted	152852	1
Double-acting cylinder	152857	1
Hydraulic motor	152858	1
Diaphragm accumulator	152859	1
Weight, 9 kg	152972	1
4/2-way hand lever valve	152974	1
4/3-way hand lever valve with bypass mid-position	152977	1
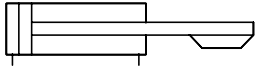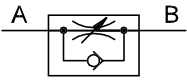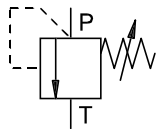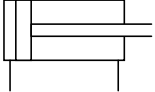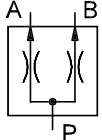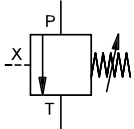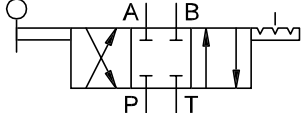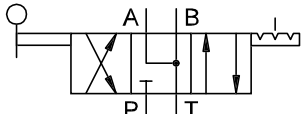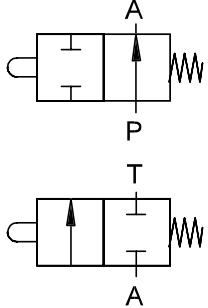
Description	Order No.	Qty.
Mounting kit for cylinder	120778	1
One-way flow control valve	152843	1
Branch tee	152847	4
Pressure relief valve	152848	1
Cylinder	152857	1
Flow-dividing valve	152967	1
Shut-off valve	152968	1
4/3-way hand lever valve closed in mid-position	152975	1
4/3-way hand lever valve with relieving mid-position	152976	1
2/2-way stem-actuated valve	152978	1

Description	Order No.	Qty.	
Relay, 3-fold	011087	1	*Additional equipment*
Signal input unit, electrical	011088	1	
Stop-watch	151504	1	
4/2-way solenoid valve	152853	1	
4/3-way solenoid valve closed in mid-position	152854	1	
Limit switch, electrical	152906	1	
Universal display	152988	1	
Pressure sensor	152989	1	
Flow sensor	152991	1	

Description	Order No.	Qty.	
Cable set	030332	1	*Accessories*
Profile plate, large	030350	1	
Power supply unit	151503	1	
Hose line, 600 mm	152960	12	
Hydraulic power pack	152962	1	
Hose line, 1000 mm	15270	4	
Pressure relieving device	152971	1	
Protective cover	152973	1	

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Description	Symbol
Mounting kit for cylinder	
One-way flow control valve	A B
Branch tee	
Pressure relief valve	P T
Cylinder	
Flow-dividing valve	A B P
Shut-off valve	P X T

Symbols for equipment set TP502

Description	Symbol
4/3-way hand lever valve closed in mid-position	A B P T
4/3-way hand lever valve with relieving mid-position	A B P T
2/2-way stem-actuated valve	A P T A

Symbols for equipment set TP502

Component/exercise table for TP502

Description	Exercises													
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Mounting kit				1			1	1						
Pressure gauge	1	2	1	1	1	3	2	1	3	4	4	4	1	2
Throttle valve	1				1									
One-way flow control valve		1				1		1				1	1	
Non-return valve, opening pressure 1 bar													1	
Non-return valve, opening pressure 5 bar			2	1				4	2	3	1	2		2
Branch tee		2	5	4		4	4	6	4	8	3	7	3	6
Pressure relief valve							2		1	3	1	1		1
3-way pressure-reducing valve												1		
2-way flow control valve		1		1				1	1	1	1		1	1
Non-return valve, piloted						1					1			
Cylinder, double-acting			2	1	1	1	1	1	1	2	1	2	1	2
Hydraulic motor	1	1												
Diaphragm accumulator						1							1	
Flow-dividing valve			1											
Weight			1			1			1		1			
4/2-way hand lever valve			1	1			1	1				1		
4/3-way hand lever v. closed in mid-position							1							
4/3-way hand lev. v. with relieving mid-position					1	1					1			
4/3-way hand lev. v. with bypass mid-position	1	1							1	1		1		
2/2-way stem-actuated valve				1			1	1						
Hydraulic power pack	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Hose line, 600 mm	2	6	5	6	6	6	7	7	4	10	5	9	7	9
Hose line, 1000 mm	2	2	4	2	2	4	2	2	4	3	4	2	2	3
Hydraulic motor with flow sensor	1	1												
Cable set	1	1												1
Power supply unit	1	1												1
Stop-watch	1			1	1			1					1	

Electrical equipment for exercise 14

Description	Order No.	Qty.
Relay, 3-fold	011087	2
Signal input unit	162242	1
4/2-way solenoid valve	152853	1
4/3-way solenoid valve closed in mid position	152854	1
Limit switch	152906	3

The exercises appear in section A, with solutions to these in section C. The methodological structure is the same for all exercises.

Methodological structure of exercises

The exercises in section A are structured as follows:

■ Subject

■ Title

■ Training aim(s)

■ Problem definition

■ Exercise

■ Positional sketch

A worksheet then follows for use in carrying out the exercise.

The solutions in section C contain the following:

■ Hydraulic circuit diagram

■ Practical assembly

■ Equipment list

■ Solution description

■ Evaluation

■ Conclusions

Section A – Course

Hydraulics   *Subject*

Hose-reel drive system for tanker truck   *Title*

■ Familiarisation with a hydraulic motor.   *Training aims*

■ Adjustment of direction and speed of rotation.

■ Drawing the circuit diagram.   *Problem definition*

■ Practical assembly of the circuit.

■ Setting of various rotary speeds for hydraulic motor.

■ Recording the time taken for 20 revolutions of the motor in each
   case.

■ Plotting the measured values.

■ Drawing conclusions.

A-4

Exercise The hose reel of a heating-oil tanker truck is driven by a hydraulic motor. This must allow the hose to be unwound, the reel to be stopped for a lengthy period, and the hose to be wound up again. A 4/3-way valve is to be used to obtain these functions. The speed must be adjustable by means of a throttle valve.

Positional sketch
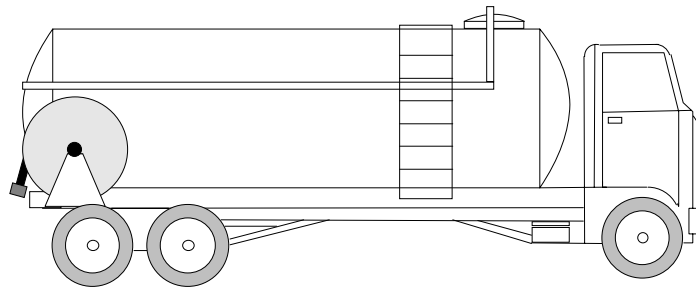
WORKSHEET

Circuit diagram, hydraulic
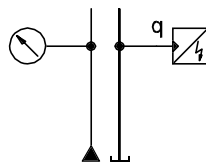
Flow rate q	Clockwise		Counterclockwise		*Evaluation*
(l/min)	Time for 20 revolutions t (s)	Speed n (rpm)	Time for 20 revolutions t (s)	Speed n (rpm)	
0,5					
1,0					
1,5					
2,0					
max.					

Speed/flow-rate characteristic

n

300 —

rpm

200 —

100 —

0 —

0   1,0   2,0 $\dfrac{l}{min}$ 3,0   q

Conclusions   What happens with the directional control valve in different switching positions?

_____

_____

What happens with different throttle valve settings?

_____

_____

What is the relationship between the rotary speed of the hydraulic motor and the flow rate?

_____

_____

Hydraulics	*Subject*
Table feed for a rough-grinding machine	*Title*

■ Familiarisation with a 2-way flow control valve. *Training aims*
■ Use of a circuit with a bypass.

■ Drawing the circuit diagram. *Problem definition*
■ Practical assembly of the circuit.
■ Pressure and flow-rate measurements.
■ Determination of power balance.
■ Drawing conclusions.

Exercise   The table feed of a grinding machine must be adjustable. Slight varia-
tions in the feed speed as a result of changes in working pressure are
permissible. The table is driven by a constant-displacement pump. An
energy-saving circuit with a 2-way flow control valve is to be developed
for this.

The power balance must be determined and compared firstly for a cir-
cuit in which the 2-way flow control valve is fitted in the bypass and sec-
ondly for a circuit in which this valve is fitted directly in the supply line to
the directional control valve. In both cases, the flow rate at the hydraulic
motor should be set to 1 l/min., with a counter-pressure of 20 bar.

Positional sketch
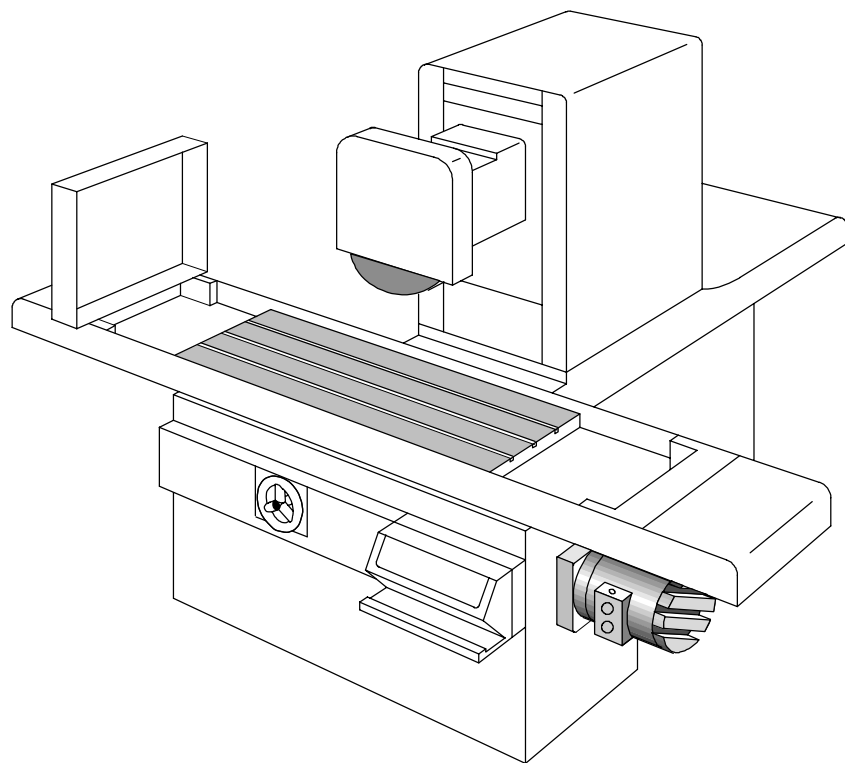
WORKSHEET
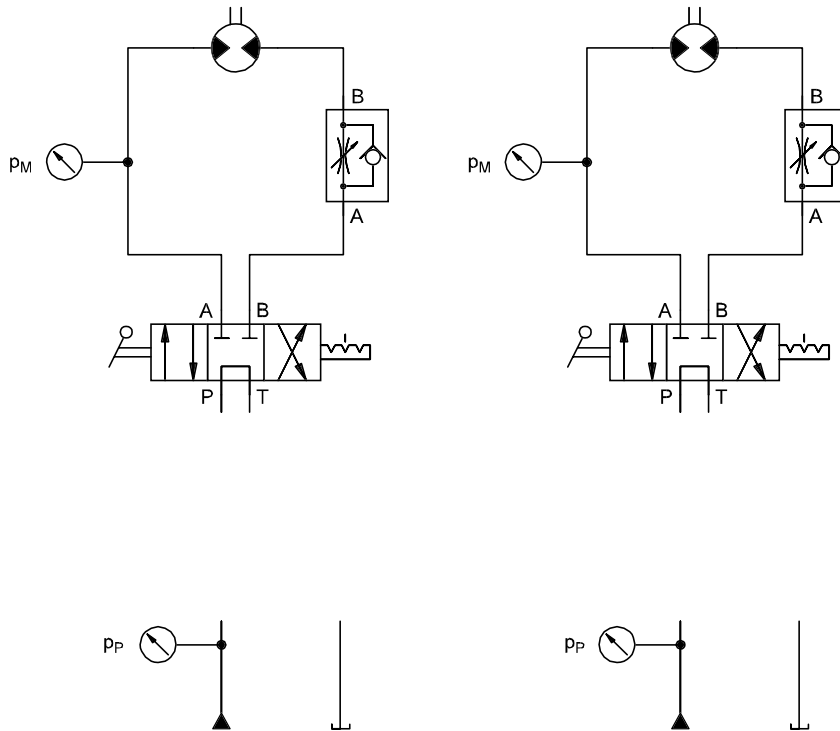
Circuit diagram, hydraulic

	Pressure upstream of FCV (bar)	Pressure downstream of FCV (bar)	Flow rate at FCV (l/min)	*Evaluation*
FCV in inlet				
FCV in bypass				

Power output of hydraulic motor:

$$P_M = p_M \cdot q_M$$

$$P_M =$$

Power balance with flow control valve in inlet line

Drive power of hydraulic pump

$$P_P = p_P \cdot q_P$$

$$P_P =$$

. . . .

Power loss

$$P_V =$$

. . . .

Power balance with flow control valve in bypass

Drive power of hydraulic pump

$$P_P =$$

. . . .

Power loss

$$P_V =$$

. . . .

Calculation of power loss via bypass

$$P_V = p_V \cdot q_V$$

$$P_V =$$

. . . .

Conclusions   Which position of the 2-way flow control valve results in more favourable energy consumption?

_____

_____

Hydraulics   *Subject*

Lifting device with two cylinders   *Title*

■ Flow divider for synchronous running of two cylinders.   *Training aims*

■ Drawing the circuit diagram.   *Problem definition*

■ Practical assembly of the circuit.

■ Studying the use of a flow divider to obtain synchronous running.

■ Drawing conclusions.

A-12

Exercise 3

Exercise A lifting device for heavy loads in equipped with two hydraulic cylinders. In order for this to operate correctly, the two piston rods connected to the table must both advance at the same speed, even when subjected to a one-sided load. A circuit must be developed using a flow divider. Two non-return valves are required to guide the return flow of hydraulic fluid past the flow divider. A weight is placed on one cylinder to demonstrate a one-sided load.

Positional sketch
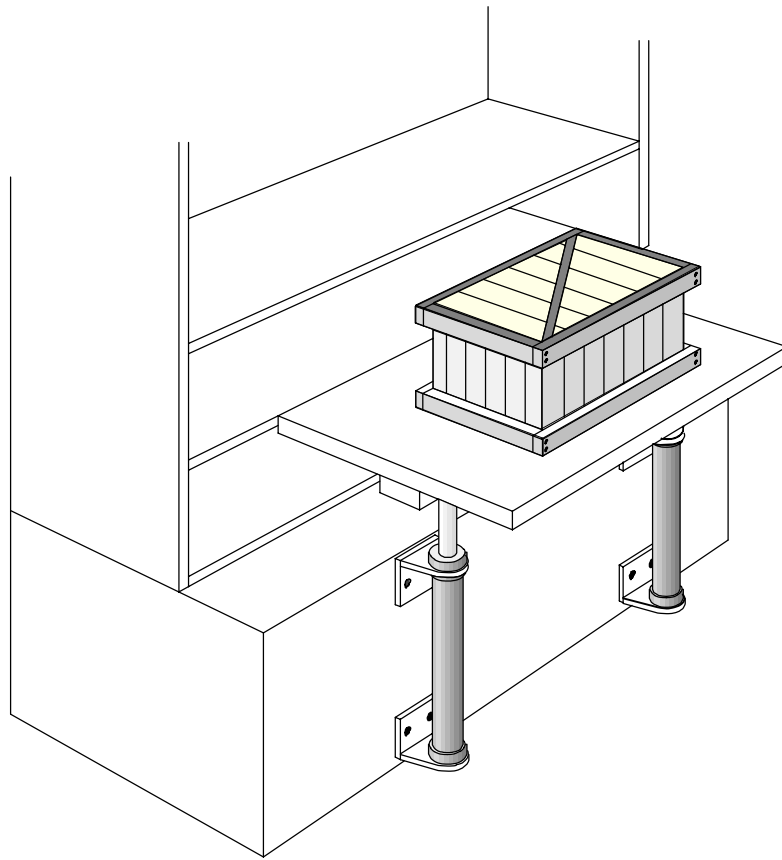
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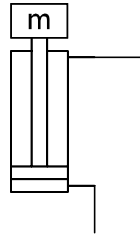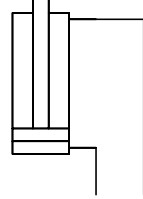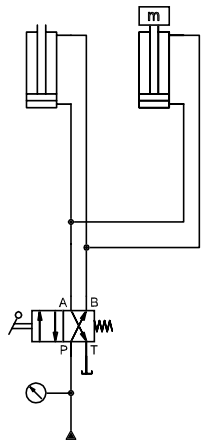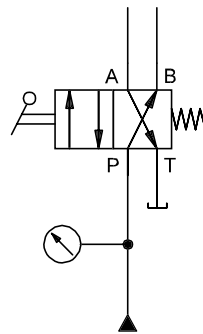
Conclusions Which cylinder advances first when the circuit has no flow divider?

What is the effect of fitting the flow divider when the cylinders are subjected to unequal loads?

Hydraulics   *Subject*

Rapid-traverse feed device for a drilling machine   *Title*

■ Familiarisation with a rapid-traverse feed circuit.   *Training aims*

■ Drawing the circuit diagram.   *Problem definition*

■ Plotting a displacement-step diagram.

■ Practical assembly of the circuit.

■ Adjusting the feed speed by means of the 2-way flow control valve.

■ Measurement of advance-stroke times.

■ Calculation of advance-stroke speeds.

■ Drawing conclusions.

Exercise Machine tools are often fitted with so-called rapid-traverse feed circuits. The drilling machine shown here is required to advance to the workpiece at a rapid-traverse speed and then drill the workpiece using a lower feed speed. The rapid-traverse speed allows shorter production times to be achieved. The feed speed must be adjustable to allow it to be matched to the material and drill-bit diameter in question.

The solution of this exercise requires the development of a circuit with a 4/2-way hand lever valve. The switchover from rapid traverse to feed speed is initiated by a 2/2-way stem-actuated valve, in turn actuated via a cam attached to the cylinder. The feed speed must be adjustable by means of a 2-way flow control valve. A bypass must be provided for the flow control valve via a non-return valve to allow the return stroke to be executed at maximum speed.

Positional sketch

WORKSHEET

Circuit diagram, hydraulic

Displacement/step diagram

Components			Time									
			Step									
Description	Desig-nation	Signal	1	2	3	4	5	6	7	8	9	10

Evaluation

2-way flow control valve (turns open)	Rapid traverse: Time for s_1 t_1 (s)	Piston speed v_1 (m/min)	Feed: Time for s_2 t_2 (s)	Piston speed v_2 (m/min)
½				
1				
1 ½				
2				
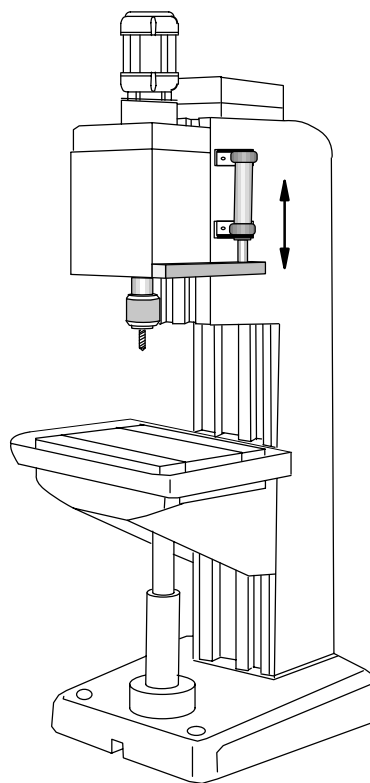
Stroke for rapid traverse: $s_1 = 150$ mm
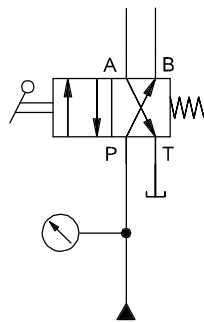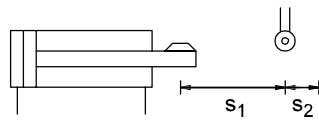
Stroke for feed: $s_2 = 50$ mm

WORKSHEET

Advance-stroke speeds

$$v = \frac{s}{t}$$

$s_1 =$ Stroke for rapid traverse, $t_1 =$ Time for rapid traverse
(no flow control operative)

$v_1 =$
. . . .

$s_2 =$ Stroke for feed, $t_2 =$ Time for feed (flow control operative)

$v_2 =$
. . . .

How is the switchover from rapid traverse to feed motion achieved?   *Conclusions*

What is the effect of the 2-way flow control valve?

Hydraulics   *Subject*

Control system for a scrap press   *Title*

■ Familiarisation with a differential circuit.   *Training aims*

■ Drawing the circuit diagram.   *Problem definition*
■ Practical assembly of the circuit.
■ Measurement of travel times.
■ Calculation of stroke speeds.
■ Calculation of area ratio.
■ Calculation of pressure forces.
■ Drawing conclusions.

Exercise The moving jaw of a scrap press is actuated by a double-acting hydraulic cylinder. The cylinder is required to advance faster at the start of the pressing operation, when the required press force is still low, than at the end, at which time a higher press force is required. The volume of oil on the piston-ring side is to be used as an additional source for the rapid-traverse advance stroke. This is achieved by means of a 4/3-way hand lever valve. A throttle valve is provided for speed adjustment.

Positional sketch

WORKSHEET

Circuit diagram, hydraulic

Throttle valve (scale divisions open)	Advance stroke without differential circuit		Advance stroke with differential circuit		Return stroke		*Evaluation*
Switching position	a		0		b		
	Time for 1 stroke t(s)	Speed v (m/min)	Time for 1 stroke t (s)	Speed v (m/min)	Time for 1 stroke t(s)	Speed v (m/min)	
½							
1							

s   =   200 mm

d_{PN} =   16 mm

d_{PR} =   8 mm

Cylinder stroke speed

$$v = \frac{s}{t}$$

$v =$

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Calculation of areas

Piston plain area

$$A_{PN} = \frac{\pi}{4} \cdot d_{PN}^2$$

$A_{PN} =$

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Cross-sectional area of piston rod

$$A_{PR} = \frac{\pi}{4} \cdot d_{PR}^2$$

$A_{PR} =$

<div style="border-bottom: 1px dashed;"></div>

Piston annular area

$$A_{AN} = A_{PN} - A_{PR}$$

$A_{AN} =$

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Area ratio

$$\alpha = \frac{A_{PN}}{A_{AN}}$$

$\alpha =$

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WORKSHEET

Calculation of forces

Cylinder advance stroke, force acting on piston area

p = Pressure at system pressure relief valve, set to 60 bar

$$F_{adv} = p \cdot A_{PN}$$

$$F_{adv} =$$

Cylinder return stroke, force acting on piston annular area

$$F_{ret} = p \cdot A_{AN}$$

$$F_{ret} =$$

Force calculation with differential circuit:
(return-stroke force working against advance-stroke force)

$$F_{diff} = F_{adv} - F_{ret}$$

$$F_{diff} =$$

	Advance stroke without differential circuit	*Advance stroke with differential circuit*	*Return stroke*	*Evaluation*
Switching position	a	0	b	
F (N)				

Conclusions   What components does the differential circuit include?

_____

_____

_____

_____

What is the effect of the differential circuit on the advance-stroke speed?

_____

_____

_____

_____

What is the effect of the differential circuit on the cylinder force?

_____

_____

_____

_____

Hydraulics

Subject

Clamping a gearbox casing

Title

- Use of a hydraulic reservoir as an accumulator.

Training aims

- Clamping a gearbox casing.
- Practical assembly of the exercise.
- Reading the clamping pressure.
- Drawing conclusions.

Problem definition

Exercise   A gearbox casing is clamped hydraulically on a milling machine. As the milling operation takes a long time, the clamping pressure is to be supplied by a diaphragm accumulator. A one-way flow control valve must be installed in such a way that the accumulator can be charged quickly but discharged only via a throttle. A bypass circuit must be provided to relieve the pump and save energy.

☞   *Be sure to follow the operating instructions for the accumulator. After the control circuit is switched off, hydraulic components may be dismantled only after the accumulator pressure has been relieved and the accumulator isolated from the control circuit by means of its built-in shut-off valve. The same valve is used to relieve the accumulator to the tank. Open the valve slowly to provide a throttle effect during the relief of the pressure.*

Positional sketch
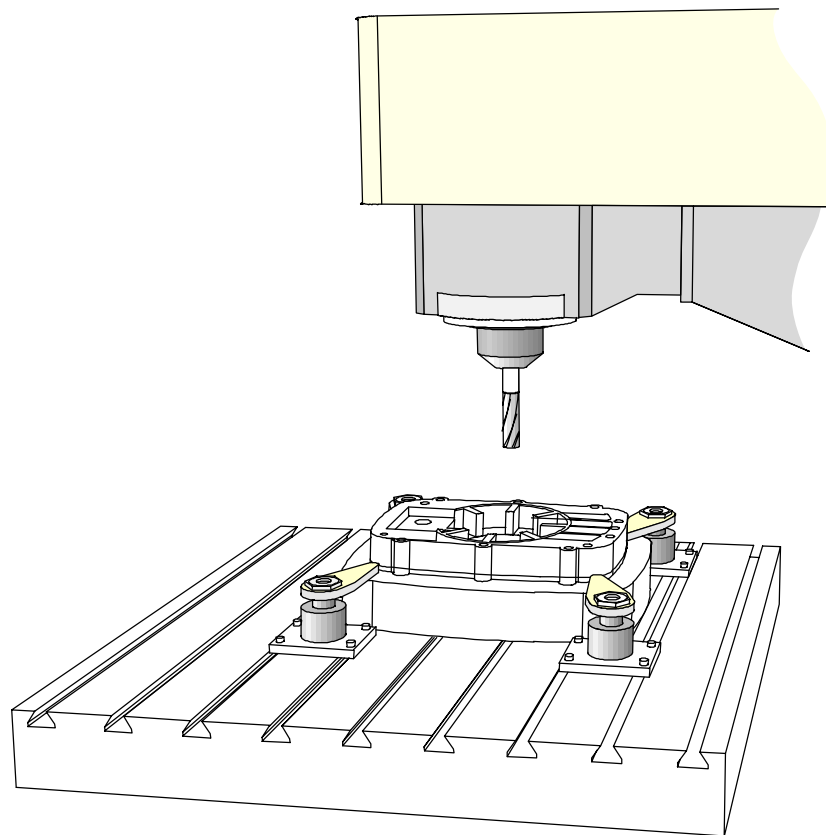
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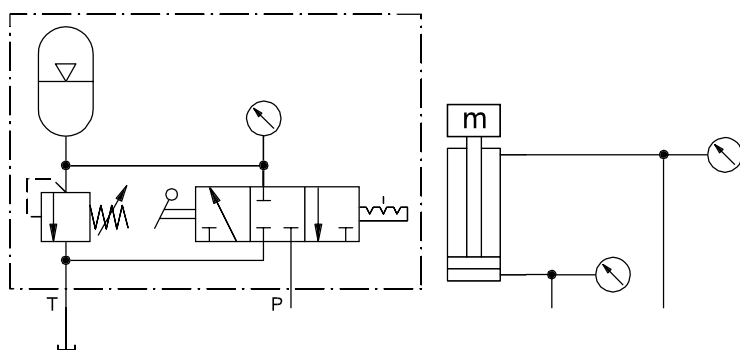
*Circuit diagram,
hydraulic*
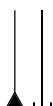
Conclusions   Why does the loaded cylinder remain in position?

_____

_____

_____

_____

Why is the cylinder able to return to its retracted end position?

_____

_____

_____

_____

Hydraulics   *Subject*

Plastic injection-moulding machine   *Title*

- Familiarisation with a dual pressure circuit.   *Training aims*

- Drawing the circuit diagram.   *Problem definition*
- Practical assembly of the circuit.
- Calculation of pressures.
- Drawing conclusions.

Exercise   The mould of a plastic injection moulding machine is filled using a low working pressure (low force). The plastic is then further moulded at high pressure (greater force). The working pressure is switched over by a roller-lever-actuated 2/2-way valve after the piston has travelled a certain distance. The necessary pressures are set on two pressure relief valves.

Positional sketch
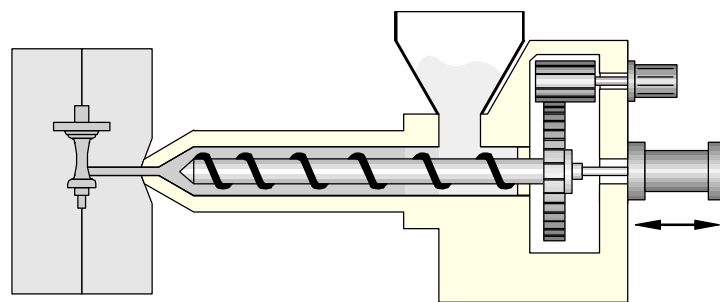
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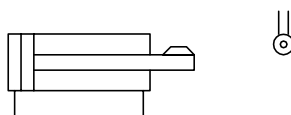
*Circuit diagram,
hydraulic*
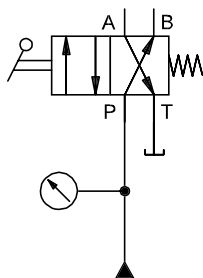
	Piston force F (N)	Working pressure p(bar)	*Evaluation*
1. Filling operation	500		
2. Moulding	1000		

d_{PN} = 16 mm

Calculation of areas

Piston plain area

$$A_{PN} = \frac{\pi}{4} \cdot d_{PN}^2$$

$$A_{PN} =$$

. . . .

Calculation of pressures

Filling pressure for piston force F_1 = 500 N:

$$p_1 = \frac{F_1}{A_{PN}}$$

$$p_1 =$$

. . . .

Moulding pressure for piston force F_2 = 1000 N:

$$p_2 = \frac{F_2}{A_{PN}}$$

$$p_2 =$$

. . . .

Conclusions Why does the pressure rise from the filling pressure to the moulding pressure?

How do you obtain the required pressures?

Hydraulics

Subject

Pipe-bending machine

Title

- Familiarisation with a rectifier circuit.

Training aims

- Drawing the circuit diagram.
- Practical assembly of the exercise.
- Calculation of travel times.
- Adjustment of speed for rapid traverse and feed.
- Drawing conclusions.

Problem definition

Exercise A rapid-traverse/feed circuit is to be developed for a universal bending machine. The working speeds of the hydraulic cylinder must be adjustable. The speed for the rapid traverse is adjusted by means of a throttle valve. After a specified travel distance, the bending operation must be executed independently of load (feed motion). A flow control valve should be used for this purpose. The return stroke over the same distance should be controlled by the same valve. The circuit should be assembled in such a way that hydraulic fluid passes through the flow control valve in the same direction during the feed motion and return stroke. The return stroke back to the starting position can be executed without a throttle function.

Positional sketch
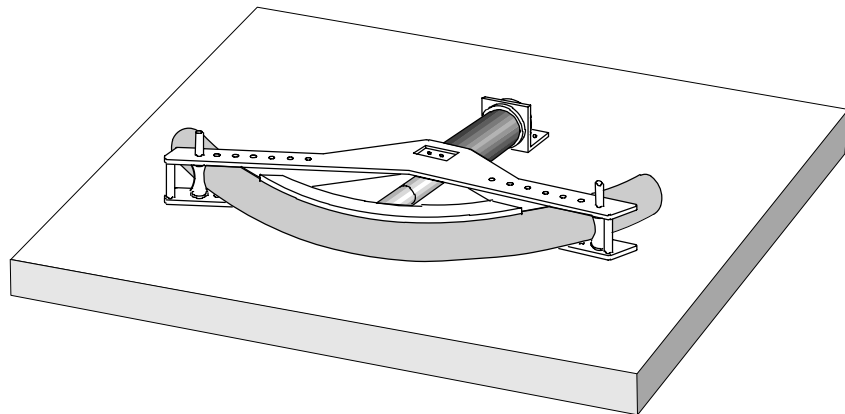
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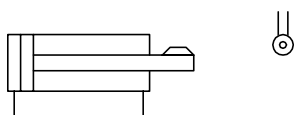
Circuit diagram, hydraulic
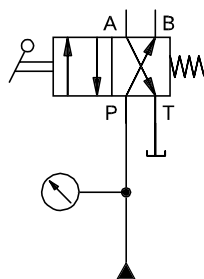
	Rapid traverse for 150 mm		Feed for 50 mm		*Evaluation*
	Time t_1 (s)	*v_1 (m/min)*	*Time t_2 (s)*	*v_2 (m/min)*	
Advance stroke					
(Return stroke)					

Stroke for rapid traverse: $s_1 = 150$ mm

Stroke for feed: $s_2 = 50$ mm

One-way flow control valve: Open ½ scale division

2-way flow control valve: Open 2 turns

Calculation of speeds:

$$v = \frac{s}{t}$$

Advance-stroke speed during rapid traverse, t_1 measured:

$v_1 =$

. . . .

Advance-stroke speed during feed, t_2 measured:

$v_2 =$

. . . .

Conclusions What is the flow through the 2-way flow control valve during the return stroke of the cylinder?

How does the rectifier circuit work?

Hydraulics

Subject

Single-column press

Title

■ Familiarisation with use of flow control valves in inlet and outlet lines.

Training aims

■ Familiarisation with counter-holding.

■ Practical assembly of the specified circuits.

Problem definition

■ Drawing the circuit diagram.

■ Practical assembly of student's circuit.

■ Drawing conclusions.

Exercise   Hydraulic single-column presses are equipped with rapid-traverse feed circuits to allow the idle stroke of the ram to be completed as quickly as possible and the pressing operation to be carried out at an appropriate speed. In this exercise, we shall consider only the control circuit for the feed speed. It should be noted that the press ram is subjected to tractive loads. These must be absorbed in order to ensure that no uncontrolled rapid-traverse or feed motions result. The flow control valve can be fitted in the inlet or outlet line. This produces different pressures in the cylinder chambers. A circuit must be developed which avoids the disadvantages of the two specified circuits. A weight should be used to produce a tractive load.

Positional sketch

WORKSHEET
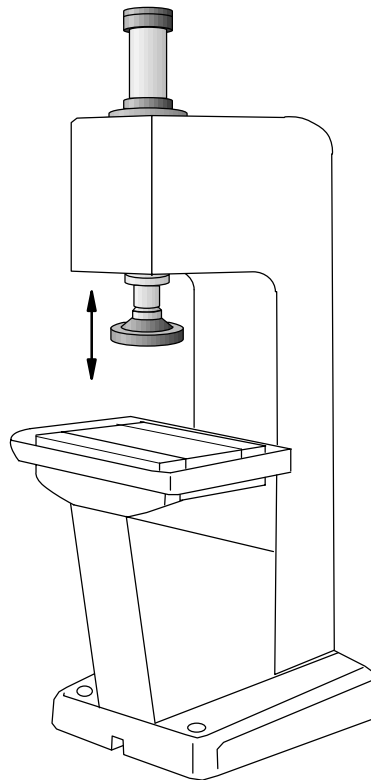
Circuit diagram, hydraulic
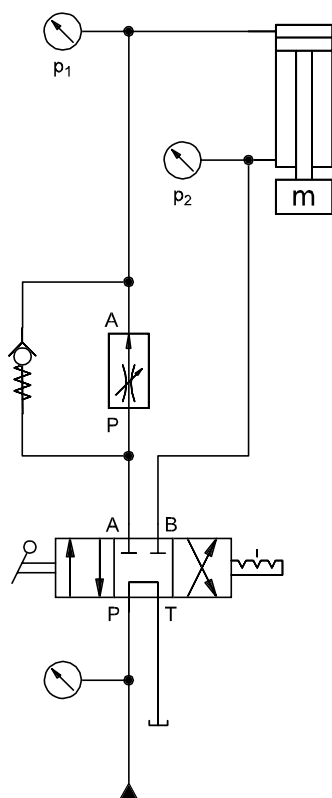
Circuit diagram 1:
Flow control valve in inlet
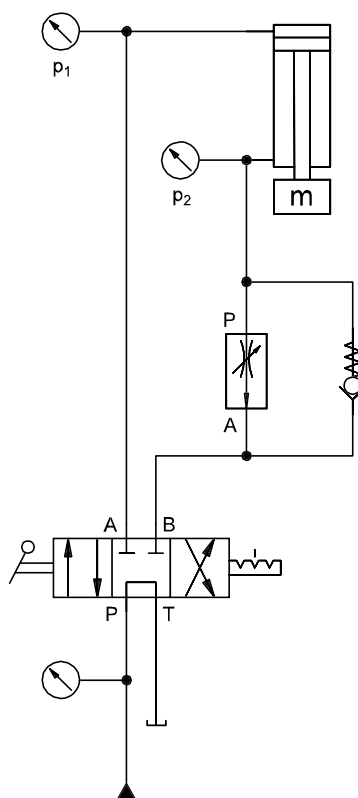
Circuit diagram 2:
Flow control valve in outlet

Circuit diagram,
hydraulic
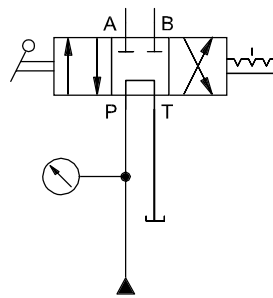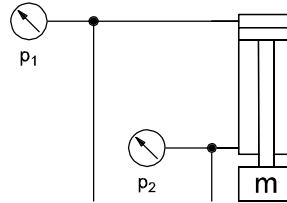
Evaluation	Variations of circuit	Pressure on piston side p_1 (bar)	Pressure on annular piston side p_2 (bar)
	Circuit 1 with flow control valve in inlet		
	Circuit 2 with flow control valve in outlet		
	New circuit		

WORKSHEET

What disadvantage results with circuit 1?

Conclusions

_____

_____

_____

_____

What disadvantage results with circuit 2?

_____

_____

_____

_____

What type of valve avoids the disadvantages of circuits 1 and 2?

_____

_____

_____

_____

Hydraulics

Subject

Machining centre

Title

- Familiarisation with sequence control with two cylinders.
- Familiarisation with pressure sequence circuit.

Training aims

- Drawing the circuit diagram.
- Drawing the displacement/step diagram.
- Practical assembly of circuit.
- Drawing conclusions.

Problem definition

Exercise A machining centre is used to mill the control edges of the outlet ports of a motorcycle cylinder barrel. The motorcycle cylinder is clamped hydraulically to the milling table by means of a clamping cylinder. When the preset clamping pressure is reached, the feed cylinder advances the milling cutter, which is driven electrically. At the end of the machining operation, the milling cutter must be retracted with its drive motor still running. The clamping cylinder must not open until the feed cylinder has completed is return stroke.

A pressure sequence circuit must be assembled for the clamping cylinder and feed cylinder. The clamping pressure is to be 30 bar. The feed cylinder must be provided with speed adjustment and counter-holding.

A pressure sequence circuit is also to be used to control the order in which the cylinders retract. A pressure sequence valve enables the return stroke of the clamping cylinder only when a pressure of 30 bar has been reached.

Positional sketch
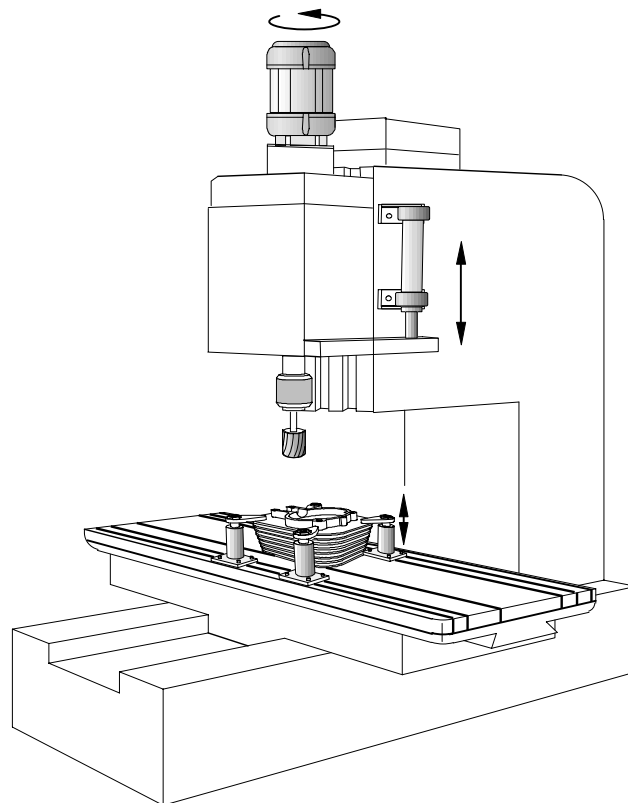
WORKSHEET

Circuit diagram, hydraulic

Displacement/step diagram

Components			Time
			Step
Description	Desig-nation	Signal	1 2 3 4 5 6 7 8 9 10
4/3-way hand lever valve	1V1	a	
		0	
		b	
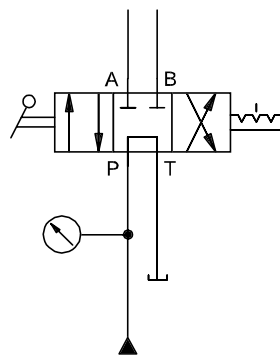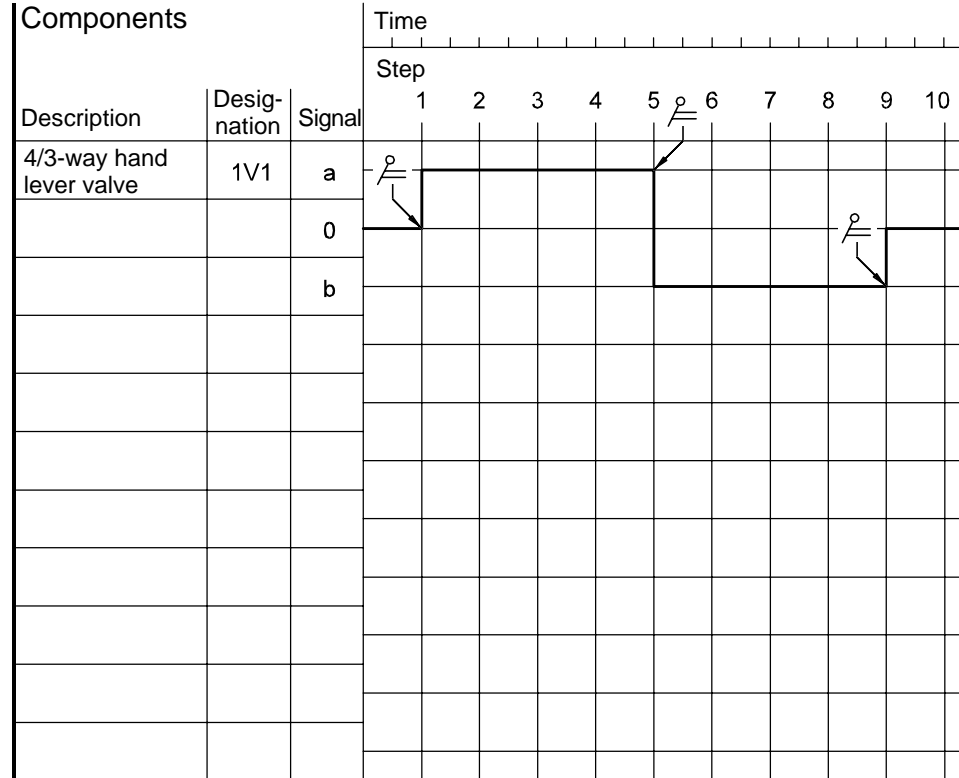
Conclusions   Which valve is used as a pressure sequence valve?

_____

_____

_____

_____

Why is this circuit called a "pressure sequence circuit"?

_____

_____

_____

_____

Hydraulics

Subject

Magnetic crane

Title

- Familiarisation with a safety device for a tractive load.

Training aims

- Drawing the circuit diagram.

Problem definition

- Practical assembly of the circuit.
- Drawing conclusions.

Exercise   A magnetic crane is fitted with a boom arm actuated by a hydraulic cylinder. The cylinder is subject to tractive loads, which must be absorbed. The cylinder must be capable of being stopped in any position. The hydraulic circuit must ensure that the load remains in the desired position. A pressure relief valve must be fitted in the circuit to provide counterholding and ensure that the cylinder can execute a controlled advance stroke.

Positional sketch

WORKSHEET

*Circuit diagram,
hydraulic*

m
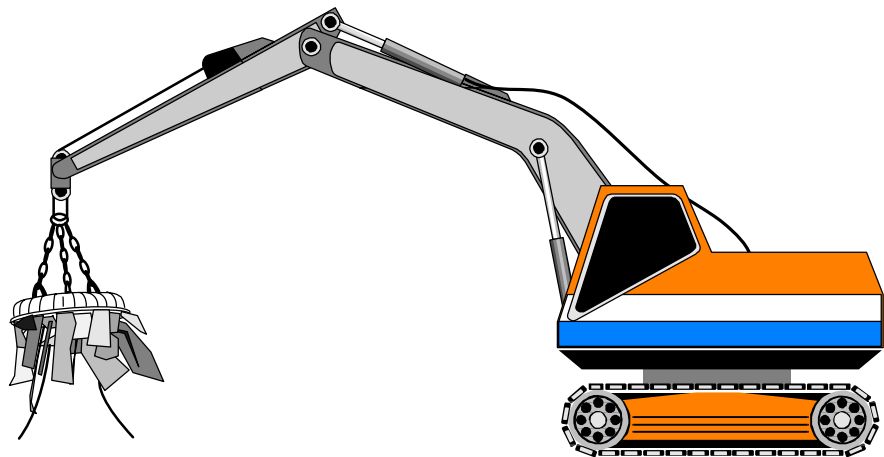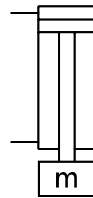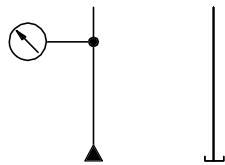
Conclusions   How is the cylinder held in position?

_____

_____

_____

_____

How is the cylinder able to advance?

_____

_____

_____

_____

Hydraulics

Subject

Folding machine

Title

■ Familiarisation with the function and use of a pressure regulator.

Training aims

■ Drawing the circuit diagram.

Problem definition

■ Plotting the displacement/step diagram.

■ Practical assembly of the exercise.

■ Calculation of clamping pressure.

■ Drawing conclusions.

Exercise Sensitive workpieces are clamped in a folding machine and folded. The clamping force must be adjustable and must be limited in this exercise to 600 N. The folding cylinder must not advance until the specified pressure of 40 bar has been reached. The folding speed of this cylinder must also be adjustable as appropriate to the material to be folded.

Positional sketch
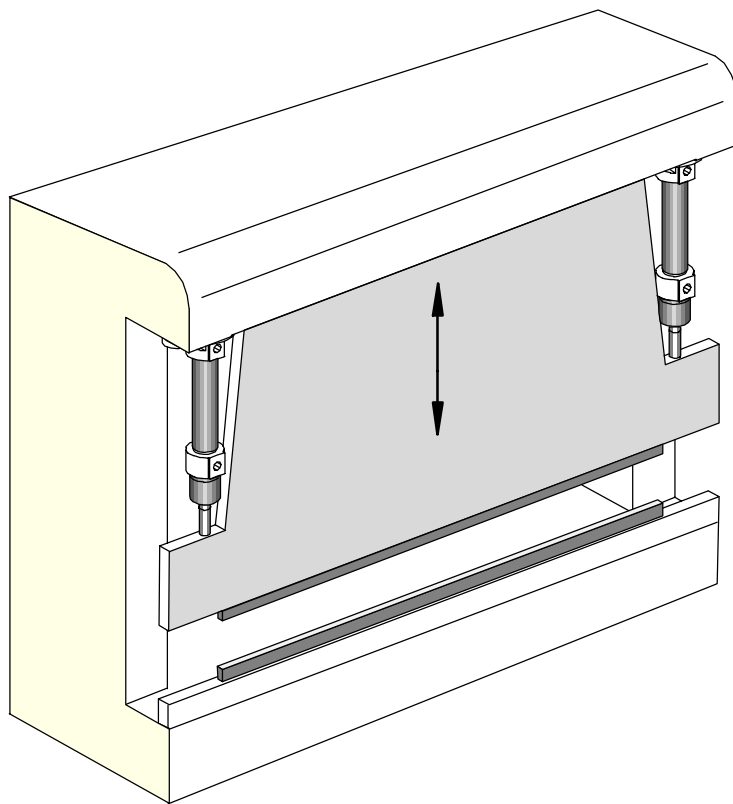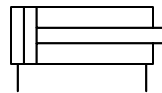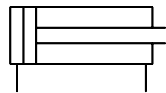
WORKSHEET

Circuit diagram, hydraulic

Displacement/step diagram

Components

Description	Desig-nation	Signal	Time										
			Step										
			1	2	3	4	5	6	7	8	9	10	
4/3-way hand lever valve	1V1	a											
		0											
		b											
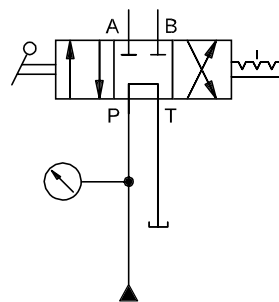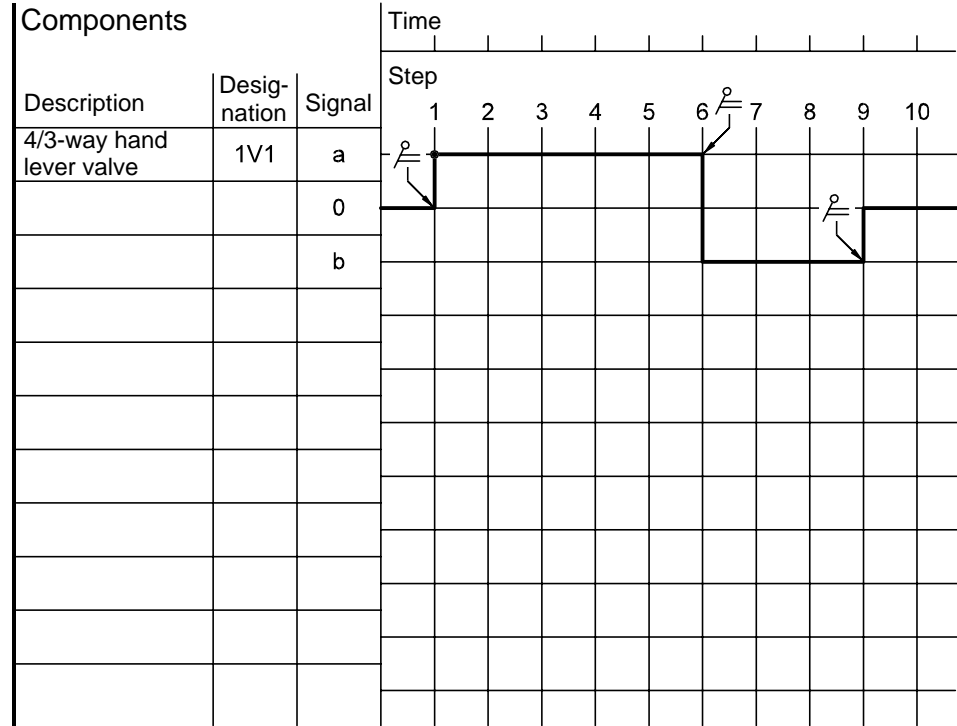
Piston diameter: d_{PN} = 16 mm
Clamping force: F = 600 N

Calculation of area

Piston area

$$A_{PN} = \frac{\pi}{4} \cdot d_{PN}^2$$

$$A_{PN} =$$

. . . .

WORKSHEET

Calculation of pressure

Clamping pressure for piston force F

$$p = \frac{F}{A_{PN}}$$

p =

. . . .

What advantage does the pressure regulator offer in comparison with a pressure relief valve?   *Conclusions*

What disadvantage must on the other hand be accepted?

Hydraulics   Subject

Earth drill   *Title*

- Use of a hydraulic accumulator for a rapid-traverse circuit.   *Training aims*

- Drawing the circuit diagram.   *Problem definition*
- Practical assembly of the circuit.
- Measurement of return-stroke times.
- Calculation of return-stroke speeds.
- Calculation of oil volumes.
- Drawing conclusions.

Exercise   The boring tools of an earth drill are driven by a hydraulic motor. The earth drill is lowered slowly by a hydraulic cylinder at a speed appropriate to the material to be drilled. The return stroke of the drill is to be executed as quickly as possible. This brief motion requires a higher volumetric flow of hydraulic fluid than the pump can deliver. This is produced by the additional installation of an accumulator.

☞   *Be sure to observe the operating instructions for the accumulator. After the control circuit has been switched off, the hydraulic components must not be dismantled until the pressure in the accumulator has been released and the accumulator has been isolated from the control circuit by means of the built-in shut-off valve. The same valve is used to relieve the accumulator to the tank. Open the valve slowly to provide a throttle effect during the relief of the pressure.*

Positional sketch
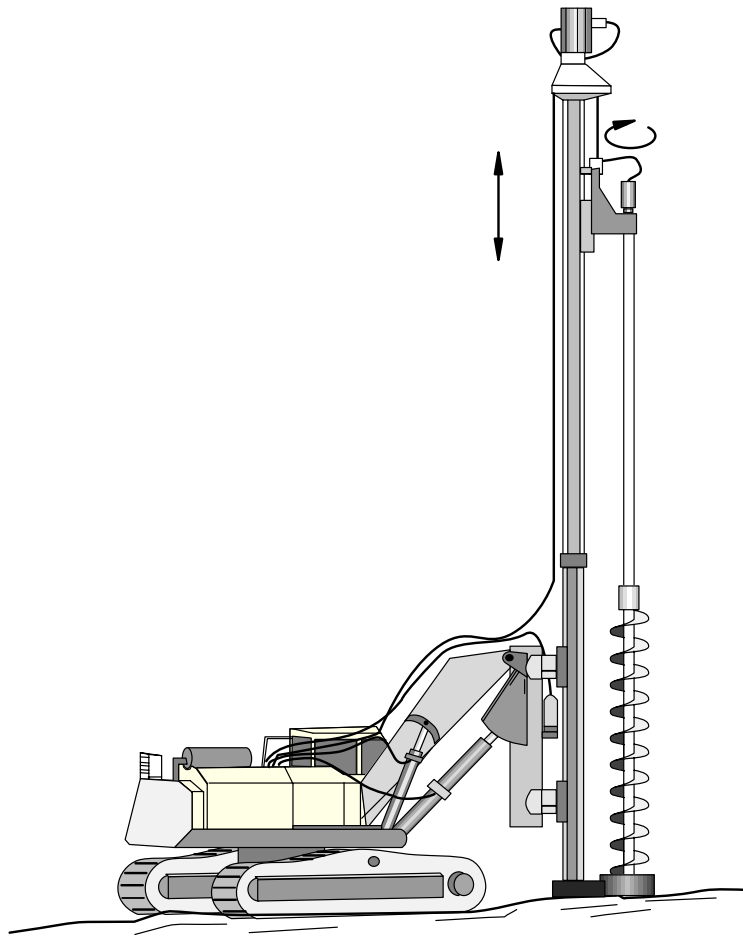
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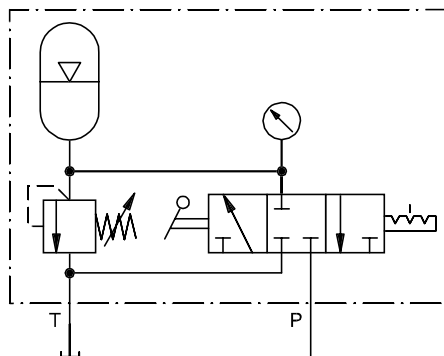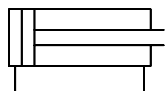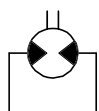
Circuit diagram, hydraulic
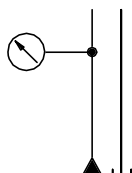
Stroke: s = 200 mm
Piston annular area: A_{PR} = 122,5 mm^2
Pump delivery: q_P = 2,2 l/min

Evaluation	Return stroke without accumulator		Return stroke with accumulator	
	Time for 1stroke t_0 *(s)*	*Speed* v_0 *(m/min)*	*Time for 1stroke* t_1 *(s)*	*Speed* v_1 *(m/min)*

Calculation of speeds

Return-stroke speed without diaphragm accumulator, t_0 measured:

$$v_0 = \frac{s}{t_0}$$

$v_0 = $

. . . .

Return-stroke speed with diaphragm accumulator, t_1 measured:

$$v_1 = \frac{s}{t_1}$$

$v_1 = $

. . . .

Speed difference

$$\Delta v = v_1 - v_0$$

$\Delta v = $

. . . .

WORKSHEET

Calculation of oil volumes

Hydraulic power pack: Max. delivery in period t_1

$$V_{P,t_1} = q_P \cdot t_1$$

$$V_{P,t_1} =$$
- -

Cylinder: Volume in piston-rod chamber

$$V_Z = A_{PR} \cdot s$$

$$V_Z =$$
- -

Volumetric difference to be supplied by accumulator in period t_1

$$\Delta V = V_Z - V_{P,t_1}$$

$$\Delta V =$$
- -

What influence does the accumulator have on the return-stroke speed of the cylinder?   *Conclusions*

Hydraulics

Machining centre

- Familiarisation with a solenoid-actuated sequence control.

- Drawing the hydraulic circuit diagram.
- Drawing the electrical circuit diagram.
- Drawing the displacement/step diagram.
- Practical assembly of the circuits.
- Drawing conclusions.

Subject

Title

Training aims

Problem definition

Exercise   A sequence control for the clamping and milling of the outlet ports of a motorcycle engine is assembled using solenoid actuation. The piston rod of the clamping cylinder advances when a "Start" pushbutton is pressed and actuates a limit switch when it reaches its forward end position. This acts via relay contacts to switch on the feed cylinder. As soon as the piston rod of the feed cylinder reaches its forward end position, a further limit switch is actuated, initiating the return stroke. When the feed cylinder reaches its retracted end position, a limit switch is again actuated. This initiates the return stroke of the clamping cylinder. Finally, a third limit switch is actuated to fulfil the start condition for a new working cycle.

Positional sketch

WORKSHEET

1S1   1S2   2S
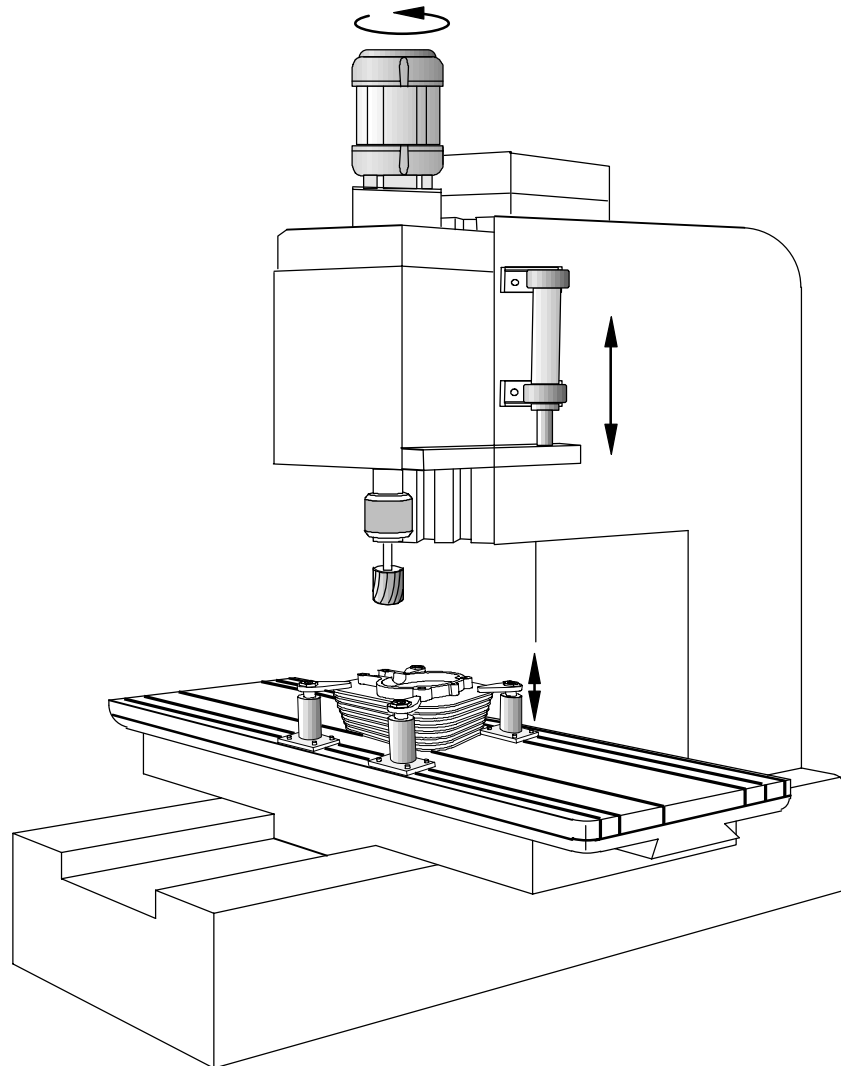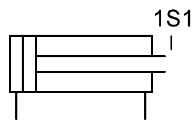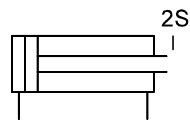
Circuit diagram, hydraulic
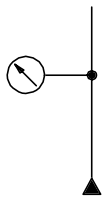
WORKSHEET

*Circuit diagram,
elektrical*
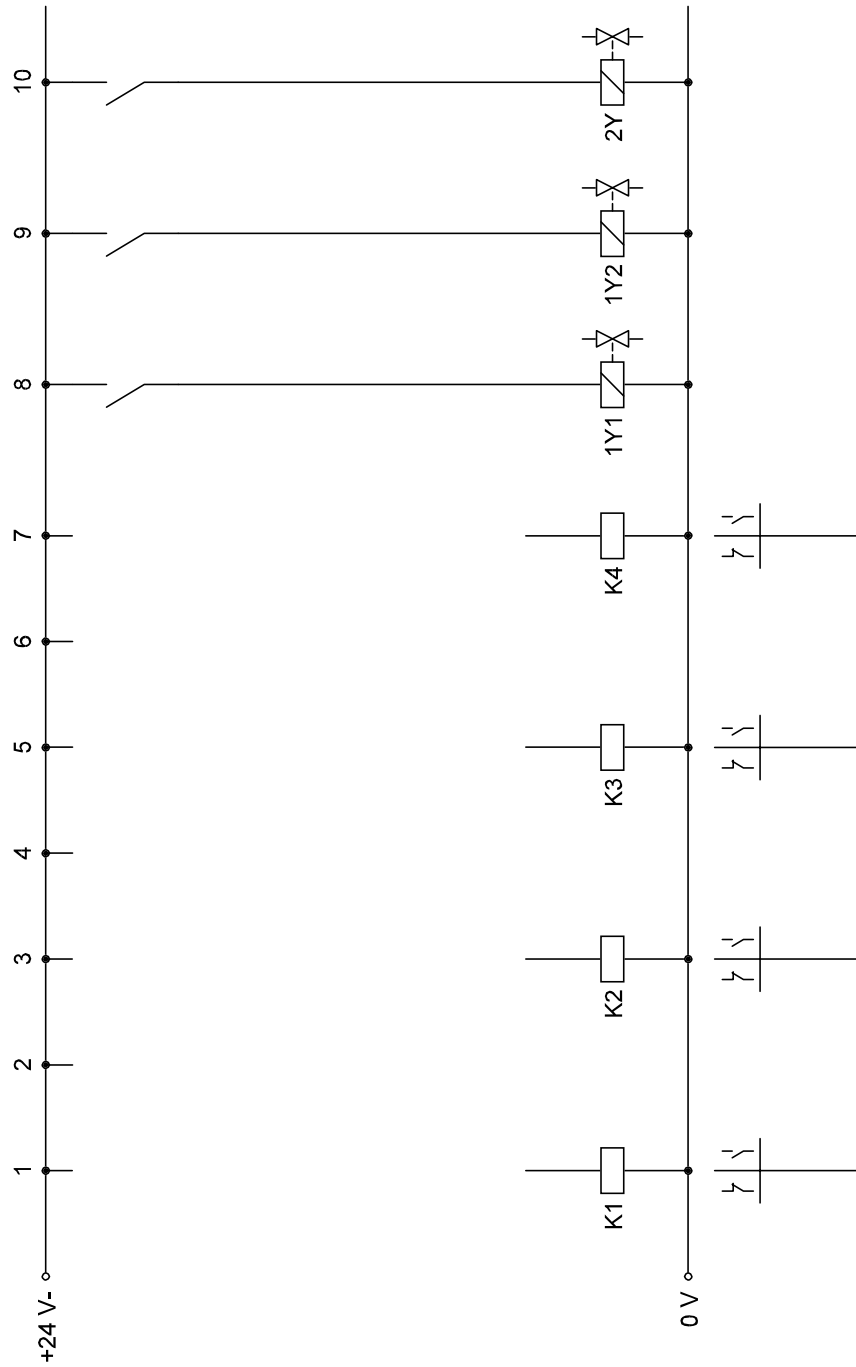
WORKSHEET

Components | | | | Time | | | | | | | *Displacement/step diagram*

Description	Desig-nation	Signal		Step
			1 2 3 4 5 6
Clamping cylinder	1A	1	
		0	
Feed cylinder	2A	1	
		0	

What is the condition for starting the installation?

Conclusions

Can a pushbutton be used as an EMERGENCY STOP pushbutton?

Section B – Fundamentals

The theoretical fundamentals for the "Hydraulics" training package are summarised in the textbook:

Hydraulics

Basic Level TP501

TN 093281

FESTO

Section C – Solutions

Hose-reel drive system for tanker truck

C-4

Practical assembly, hydraulic

Components list

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2	1	Pressure gauge
0S	1	Hydraulic motor with flow sensor
0V	1	Throttle valve
1V	1	4/3-way hand-lever valve with bypass position
1A	1	Hydraulic motor
	4	Hose line
	1	Stop-watch

Once the hydraulic circuit has been assembled, the 4/3-way hand lever valve should be brought into its mid-position. The hydraulic power pack should be switched on and the pressure relief valve closed until the pressure gauge shows 60 bar. The hydraulic motor can then be started by moving the 4/3-way valve into its right or left-hand switching position. The flow rate can be adjusted by means of the throttle valve.

Solution description

Evaluation

Flow rate q	Clockwise		Counterclockwise	
	Time for 20 revolutions	Speed	Time for 20 revolutions	Speed
(l/min)	t (s)	n (rpm)	t (s)	n (rpm)
0.5	17.5	68.6	18.2	65.9
1.0	9.5	126.3	9.5	126.3
1.5	6.3	190.4	6.2	193.5
2.0	4.8	250	4.8	250
Max.	4.3	279	4.3	279

*Speed/flow-rate
characteristic*
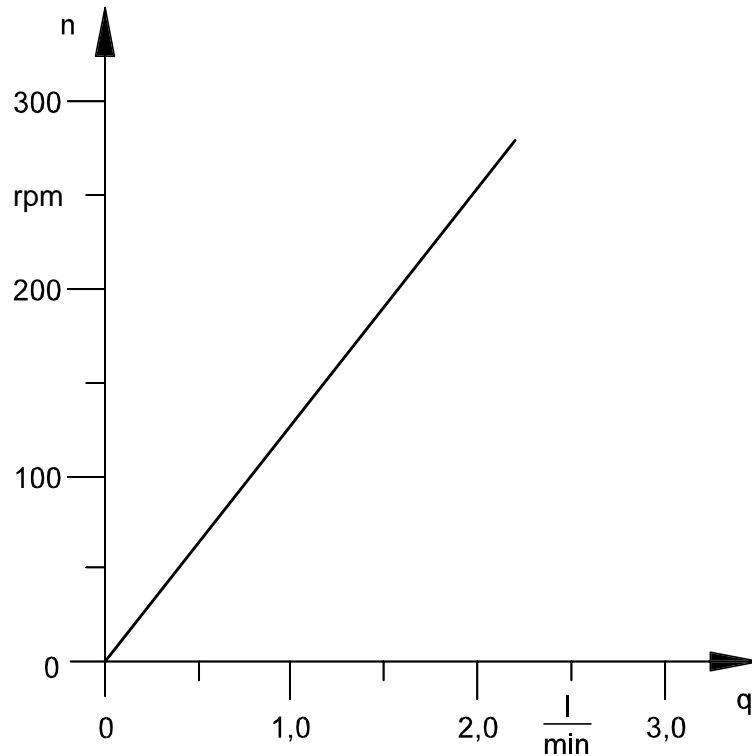
Conclusions
1. When the 4/3-way hand lever valve is actuated, the hydraulic motor changes its direction of rotation. Its mid-position provides a bypass to the tank. This helps save energy when the hydraulic motor is at a standstill.

2. Different throttle-valve positions produce changes in the speed of the hydraulic motor.

3. The speed of rotation of the hydraulic motor is proportional to the flow rate. Double the flow rate results in double speed.

Table feed for a rough-grinding machine
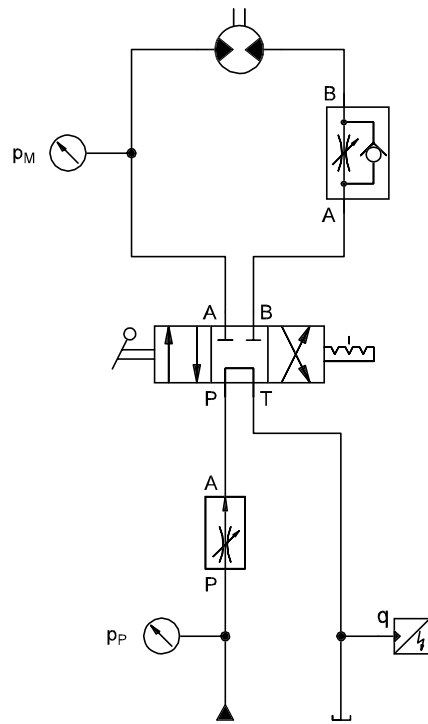
Circuit diagram 1, hydraulic

C-8

Circuit diagram 2, hydraulic
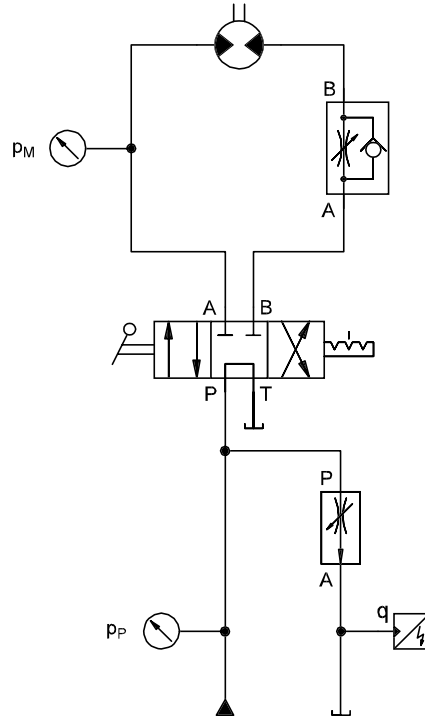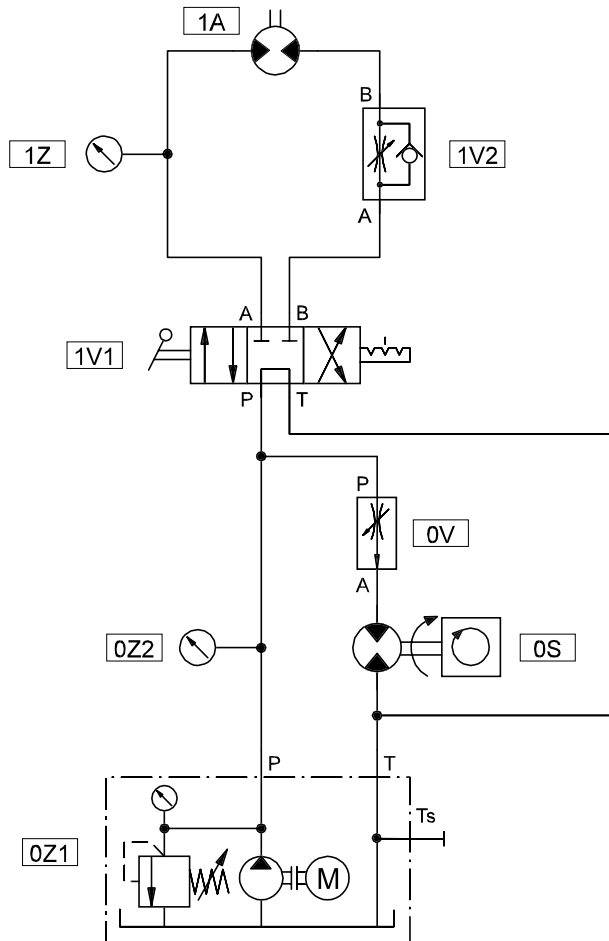
Practical assembly
hydraulic

Components list	Item no.	Qty.	Description
	0Z1	1	Hydraulic power pack
	0Z2, 1Z	2	Pressure gauge
	0V	1	2-way flow control valve
	0S	1	Hydraulic motor with flow sensor
	1V1	1	4/3-way hand-lever valve with bypass position
	1V2	1	One-way flow control valve
	1A	1	Hydraulic motor
		8	Hose line
		2	Branch tee

Solution description Once one of the hydraulic circuits has been assembled, the 4/3-way hand lever valve should be brought into its mid-position. The hydraulic power pack should be switched on and the pressure relief valve closed until the pressure gauge shows 60 bar. The hydraulic motor can then be started by moving the 4/3-way valve. Adjust the 2-way flow control valve until the flow rate at the hydraulic motor is 1.0 l/min. Use the one-way flow control valve to adjust the counter-pressure to 20 bar (as shown by the pressure gauge directly upstream of the hydraulic motor).

For both circuits, read the pressure upstream and downstream of the 2-way flow control valve and the flow rate and enter these values in the evaluation table.

☞ *If only one motor with a flow sensor is used, this should first be installed in the circuit as a hydraulic motor. After the flow rate and counter-pressure have been adjusted, this motor should be used as a flow sensor to determine flow losses. An identical motor but without a flow sensor is included in the equipment set.*

	Pressure upstream of FCV (bar)	Pressure downstream of FCV (bar))	Flow rate at FCV (l/min)	*Evaluation*
FCV in inlet	57	20	1.0	
FCV in bypass	21	0	1.2	

Power output of hydraulic motor P_M:

p_M = Pressure upstream of hydraulic motor, set to 20 bar.

q_M = Flow rate through hydraulic motor, set to 1 l/min.

$$P_M = p_M \cdot q_M$$

$$P_M = 20 \text{ bar} \cdot 1.0 \frac{l}{min} = 20 \cdot 10^5 \frac{N}{m^2} \cdot 1.0 \frac{10^{-3} \text{ m}^3}{60 \text{ s}} = 20 \cdot 1.0 \frac{10^2 \text{ Nm}}{60 \text{ s}}$$

$$P_M = 33.3 \frac{Nm}{s} = 33.3 \text{ W}$$

Power balance with flow control valve in inlet line

Drive power of hydraulic pump

p_P = Pressure upstream of flow control valve, measured.

q_P = Flow rate through flow control valve, set to 1 l/min.

$$P_P = p_P \cdot q_P$$

$$P_P = 57 \text{ bar} \cdot 1.0 \frac{l}{min} = 57 \cdot 10^5 \frac{N}{m^2} \cdot 1.0 \frac{10^{-3} \text{ m}^3}{60 \text{ s}} = 57 \cdot 1.0 \frac{10^2 \text{ Nm}}{60 \text{ s}}$$

$$P_P = 95.0 \frac{Nm}{s} = 95.0 \text{ W}$$

Power loss

$$P_V = P_P - P_M$$

$$P_V = 95.0 - 33.3 = 61.7 \text{ W}$$

Power balance with flow control valve in bypass

Drive power of hydraulic pump

p_P = Pressure upstream of flow control valve, measured.

q_P = Pump delivery for motor and flow control valve.

$$q_P = q_M + q_{FCV} = 1.0\frac{l}{min} + 1.2\frac{l}{min} = 2.2\frac{l}{min}$$

$$P_P = p_P \cdot q_P$$

$$P_P = 21\,bar \cdot 2.2\frac{l}{min} = 21\cdot 10^5\,\frac{N}{m^2}\cdot 2.2\frac{10^{-3}m^3}{60\,s} = 21\cdot 2.2\frac{10^2\,Nm}{60\,s}$$

$$P_P = 77.0\frac{Nm}{s} = 77.0\,W$$

Power loss

$$P_V = P_P - P_M$$

$$P_V = 77.0 - 33.3 = 43.7\ \ W$$

Calculation of power loss via bypass

p_v = Pressure upstream of flow control valve.

q_v = Flow rate through flow control valve.

$$P_V = p_V \cdot q_V$$

$$P_V = 21\,bar \cdot 1.2\frac{l}{min} = 21\cdot 10^5\,\frac{N}{m^2}\cdot 1.2\frac{10^{-3}m^3}{60s} = 21\cdot 1.2\frac{10^2\,Nm}{60s}$$

$$P_V = 42.0\frac{Nm}{s} = 42.0\,W$$

Conclusions   The circuit with a 2-way flow control valve in the bypass gives more fa-vourable energy consumption. The calculations reveal a lower power loss. The residual flow which is not required is discharged via the flow control valve at only the working pressure required at any given time.

Disadvantage of bypass circuit: An irregular pump delivery has a direct effect on the speed of rotation of the hydraulic motor.

Lifting device with two cylinders
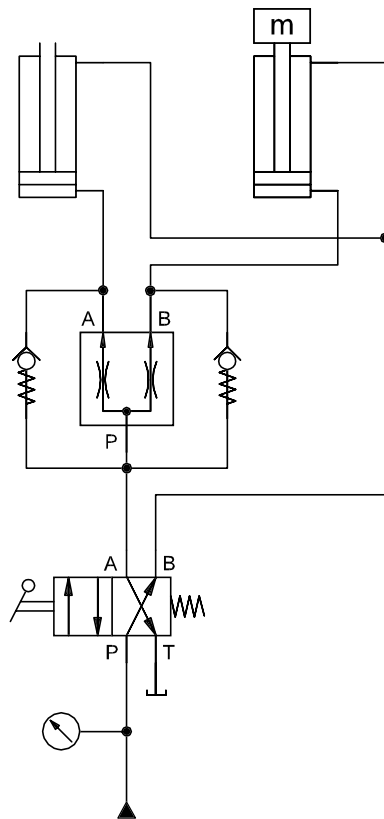
Practical assembly,
hydraulic
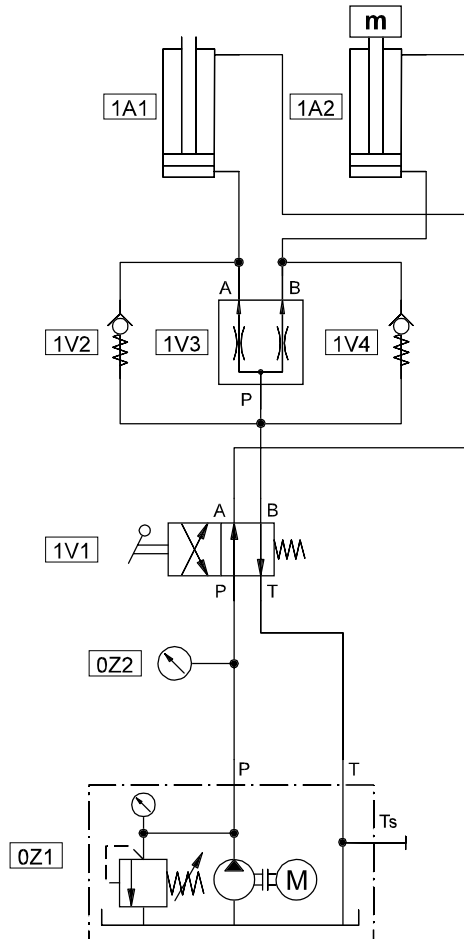
Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2	1	Pressure gauge
1V1	1	4/2-way hand-lever valve
1V2, 1V4	2	Non-return valve
1V3	1	One-way flow control valve
1A1, 1A2	2	Cylinder, double-acting
	1	Weight
	9	Hose line
	5	Branch tee

Components list

Once the hydraulic circuit has been assembled, the installation can be put into operation. The system pressure relief valve should be set to 60 bar. The cylinders are set in motion by operating the 4/2-way hand lever valve.

Solution description

Different 4/2-way hand-lever valves are used for the practical assembly and the drawing of the circuit diagram. The valve used in the practical assembly has flow from P to A and from P to B in its mid-position.

Without a flow divider, the cylinder without load is the first to advance, due to the lower resistance. As soon as the piston rod of this cylinder reaches its forward end position, the system pressure rises until the resistance of the second cylinder is overcome. The piston rod of the second cylinder will now advance to its forward end position. Following this, the pressure will rise further to the value set on the system pressure relief valve.

Conclusions

With a flow divider, the piston rods of the cylinders advance at the same time, despite the difference in their loads. The flow divider regulates the flow to the load devices in accordance with pressure conditions, with the result that both piston rods advance simultaneously. A starting surge can be observed only at the very beginning.
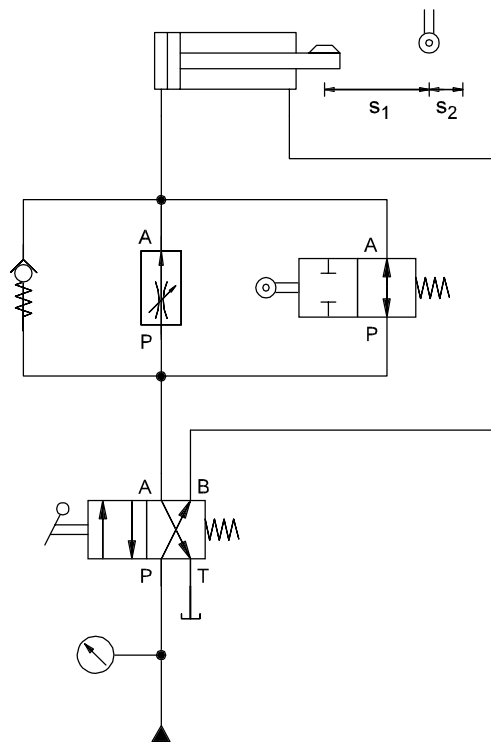
Rapid-traverse feed device for a drilling machine

*Circuit diagram,
hydraulic*
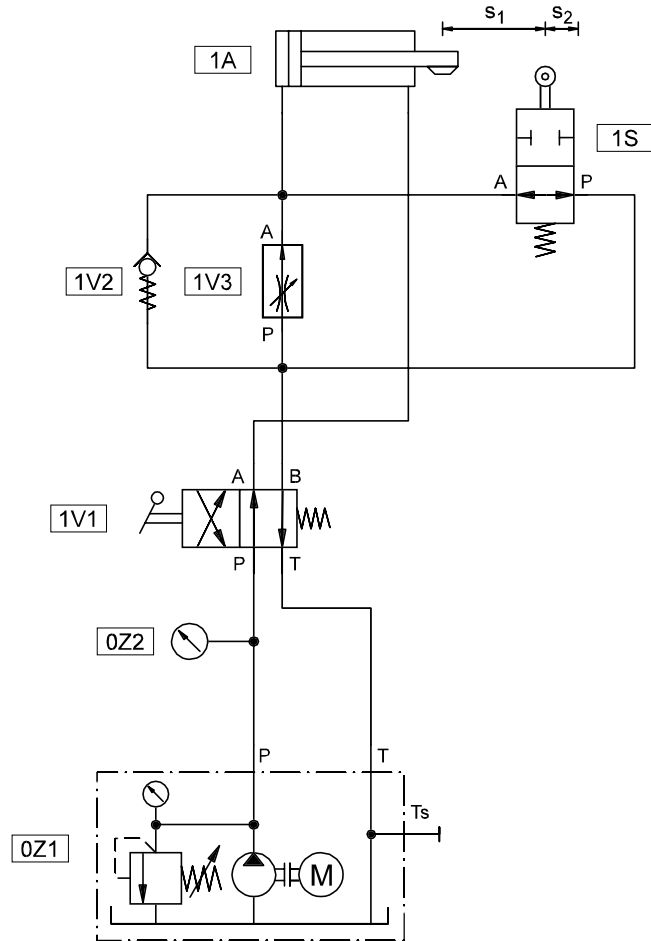
Practical assembly,
hydraulic

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2	1	Pressure gauge
1V1	1	4/2-way hand-lever valve
1V2	1	Non-return valve
1V3	1	2-way flow control valve
1S	1	2/2-way stem-actuated valve
1A1, 1A2	2	Cylinder, double-acting
	1	Mounting kit
	8	Hose line
	4	Branch tee
	1	Stop-watch
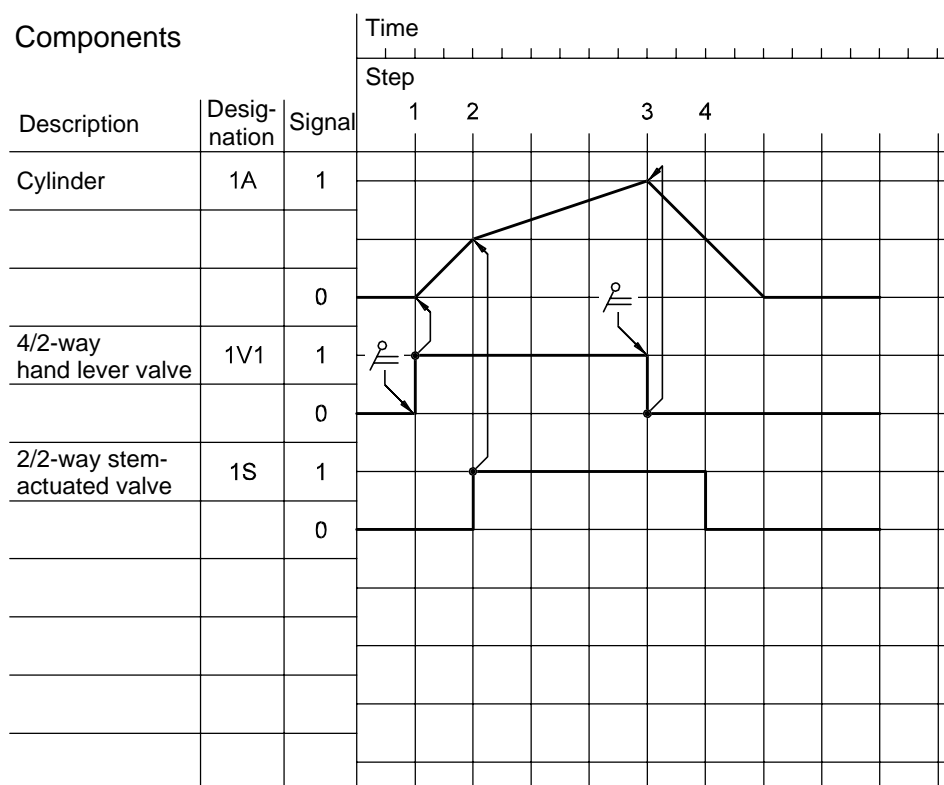
Components

Description	Designation	Signal	
Cylinder	1A	1	
		0	
4/2-way hand lever valve	1V1	1	
		0	
2/2-way stem-actuated valve	1S	1	
		0	

Once the hydraulic circuit has been assembled, the installation can be put into operation. The system pressure relief valve should be set to 60 bar. The cylinder is set in motion by operating the 4/2-way hand lever valve.

Solution description

☞ *Different 4/2-way hand-lever valves are used for the practical assembly and the drawing of the circuit diagram. The valve used in the practical assembly has flow from P to A and from P to B in its mid-position.*

Evaluation

2-way flow control valve (turns open)	Rapid traverse: Time for s_1 t_1 (s)	Piston speed v_1 (m/min)	Feed: Time for s_2 t_2 (s)	Piston speed v_2 (m/min)
½	0.7	12.9	6.7	0.4
1	0.7	12.9	1.1	2.7
1 ½	0.7	12.9	0.6	5.0
2	0.7	12.9	0.5	6.0

Advance-stroke speed

Flow control valve open ½ turn.

$$v = \frac{s}{t}$$

where $s_1 = 150 \text{ mm}$ and $t_1 = 0.7 \text{ s}$

$$v_1 = \frac{s_1}{t_1} = \frac{150 \text{ mm}}{0.7 \text{ s}} = \frac{0.15 \text{ m}}{0.7 \text{ s}} = 0.21 \frac{\text{m}}{\text{s}} \approx 12.9 \frac{\text{m}}{\text{min}}$$

where $s_2 = 50 \text{ mm}$ and $t_2 = 6.7 \text{ s}$

$$v_2 = \frac{s_2}{t_2} = \frac{50 \text{ mm}}{6.7 \text{ s}} = \frac{0.05 \text{ m}}{6.7 \text{ s}} = 0.0075 \frac{\text{m}}{\text{s}} \approx 0.4 \frac{\text{m}}{\text{min}}$$

Conclusions   The 2/2-way stem-actuated valve is used to switch over from rapid traverse to feed speed. The valve is initially open, and the cylinder advances at rapid-traverse speed. As soon as the cylinder actuates the trip cam of the 2/2-way stem-actuated valve via the cam attached to the cylinder rod, flow is shut off. Hydraulic fluid can now flow only via the 2-way flow control valve.

The 2-way flow control valve controls the feed speed. The flow of hydraulic fluid to the piston side of the cylinder varies in accordance with the valve setting.

Control system for a scrap press
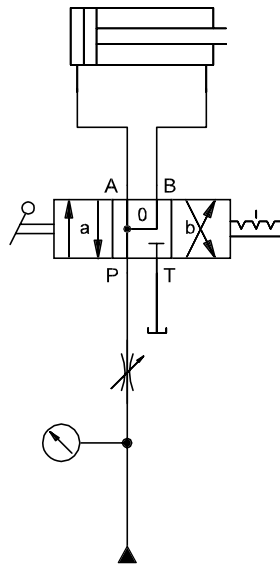
Circuit diagram, hydraulic

Practical assembly,
hydraulic

1A

1V

A   B

0

a   b

P   T

0V

0Z2

P   T

Ts

0Z1

M
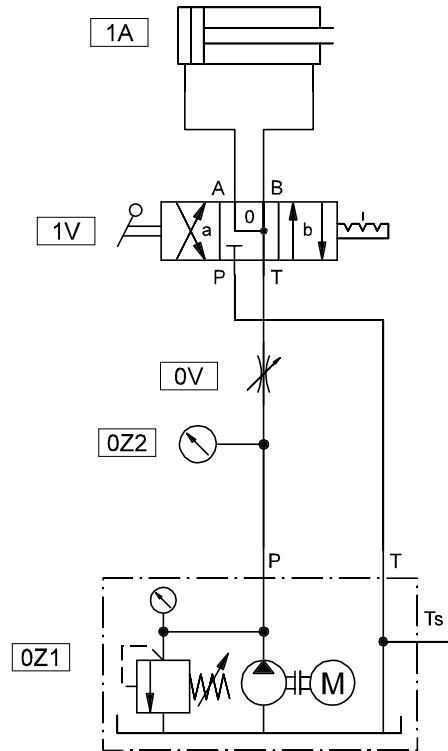
Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2	1	Pressure gauge
0V	1	Throttle valve
1V	1	4/3-way hand-lever valve
1A	1	Cylinder, double-acting
	8	Hose line
	1	Stop-watch

Components list

Once the hydraulic circuit has been assembled, the 4/3-way hand-lever valve is brought into switching position b. The hydraulic power pack should be switched on and the system pressure relief valve closed until the pressure gauge shows 60 bar. The cylinder is set in motion by bringing the 4/3-way hand-lever valve into switching position a or 0. The flow rate is controlled by means of the throttle valve.

Solution description

In order to produce a practical differential circuit, the pressure connection of the pump should be connected to port T of the 4/3-way hand-lever valve, since in the mid-position (relieved position) of this valve ports A and B are connected to the tank.

The circuit diagram and the diagram for the practical assembly thus also differ as regards the designations of switching positions a and b of the 4/3-way hand-lever valve. Once again, for the purposes of practical assembly, connection T should be regarded as the supply port P. In switching position a, the valve allows flow from P to A in the circuit diagram but from T to A in the practical assembly. Switching position b allows flow from P to B in the circuit diagram, but T to B in the practical assembly.

In both diagrams, the cylinder advance is initiated by switching position a (conventionally). Switching position 0 allows advance via the differential circuit, while switching position b allows a return stroke of the cylinder.

Evaluation		Advance stroke without differential circuit		Advance stroke with differential circuit		Return stroke	
	Switching position	a		0		b	
	Throttle valve (scale divisions open)	Time for 1 stroke t(s)	Speed v (m/min)	Time for 1 stroke t (s)	Speed v (m/min)	Time for 1 stroke t(s)	Speed v (m/min)
	½	9.0	1.3	3.8	3.2	5.7	2.1
	1	1.1	10.9	0.5	24.0	0.7	17.1

Stroke speed of cylinder

Example: Switching position a and throttle valve open ½ scale division.

$s = 200$ mm

$$v = \frac{s}{t} = \frac{200 \text{ mm}}{9.0 \text{ s}} = \frac{0.2 \text{ m}}{9.0 \text{ s}} = 0.022 \frac{\text{m}}{\text{s}} \cdot \frac{60 \text{ s}}{1 \text{min}} \approx 1.3 \frac{\text{m}}{\text{min}}$$

Calculation of areas

Piston diameter: $d_{PN} = 16$ mm

Cylinder piston area

$$A_{PN} = \frac{\pi}{4} \cdot d_{PN}^2$$

$$A_{PN} = \frac{\pi}{4} \cdot 16^2 \text{ mm}^2 = 3.14 \cdot \frac{256}{4} \text{ mm}^2 = 3.14 \cdot 64 \text{ mm}^2 = 201 \text{ mm}^2$$

Piston-rod diameter: $d_{PR} = 10$ mm

Piston-rod cross-section

$$A_{PR} = \frac{\pi}{4} \cdot d_{PR}^2$$

$$A_{PR} = \frac{\pi}{4} \cdot 10^2 \text{ mm}^2 = 3.14 \cdot \frac{100}{4} \text{ mm}^2 = 3.14 \cdot 25 \text{ mm}^2 = 78.5 \text{ mm}^2$$

Piston annular area

$$A_{AN} = A_{PN} - A_{PR}$$

$$A_{AN} = 201.0 - 78.5 = 122.5 \text{ mm}^2$$

Ratio of piston and annular piston areas

$$\alpha = \frac{A_{PN}}{A_{AN}} = \frac{201.0 \text{ mm}^2}{122.5 \text{ mm}^2} = \frac{1.64}{1} = 1.64$$

System pressure relief valve: Conversion of units

$$p = 60 \text{ bar} = 60 \cdot 10^5 \frac{N}{m^2} = 60 \cdot 10^5 \frac{N}{10^6 \text{ mm}^2} = 6 \frac{N}{mm^2}$$

Calculation of forces

Cylinder advance stroke, force acting on piston area:

$$F_{adv} = p \cdot A_{PN}$$

$$F_{adv} = 6 \frac{N}{mm^2} \cdot 201 \text{ mm}^2 = 1206 \text{ N}$$

Cylinder return stroke. force acting on annular piston area

$$F_{ret} = p \cdot A_{AN}$$

$$F_{ret} = 6 \frac{N}{mm^2} \cdot 122.5 \text{ mm}^2 = 735 \text{ N}$$

Calculation of forces with differential circuit:
(Return-stroke force opposing advance-stroke force)

$$F_{diff} = F_{adv} - F_{ret}$$

$$F_{diff} = 1206 \text{ N} - 735 \text{ N} = 471 \text{ N}$$

Evaluation

	Advance stroke without differential circuit	Advance stroke with differential circuit	Return stroke
Switching position	a	0	b
F (N)	1206 N	471 N	735 N

Conclusions   In the case of the differential circuit, the piston chamber and the annular piston chamber of the cylinder are connected to the supply port.

When a differential circuit is used, the advance-stroke speed of the piston is greater than in switching position a, since the hydraulic fluid from the piston-rod chamber also flows via the 4/3-way hand-lever valve into the piston chamber.

When a differential circuit is used, the stroke force of the advancing cylinder is lower, since an opposing force is acting on the piston-rod side. Due to the fact that the piston chamber and piston-rod chambers are connected, the same pressure is present on both sides of the piston. The counter-force acting on the piston-rod side can be calculated from the area ratio a = 1.64 : 1 (piston area to piston annular area). The piston rod advances with reduced stroke force.

Clamping a gearbox casing
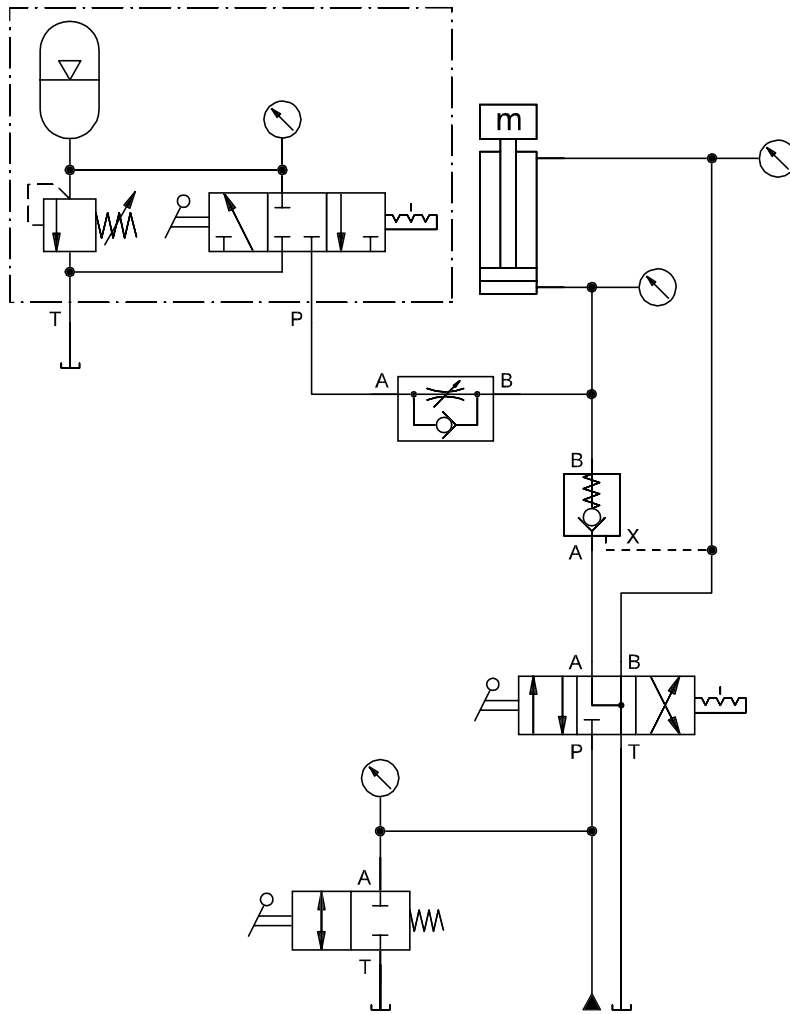
Circuit diagram, hydraulic

Practical assembly,
hydraulic

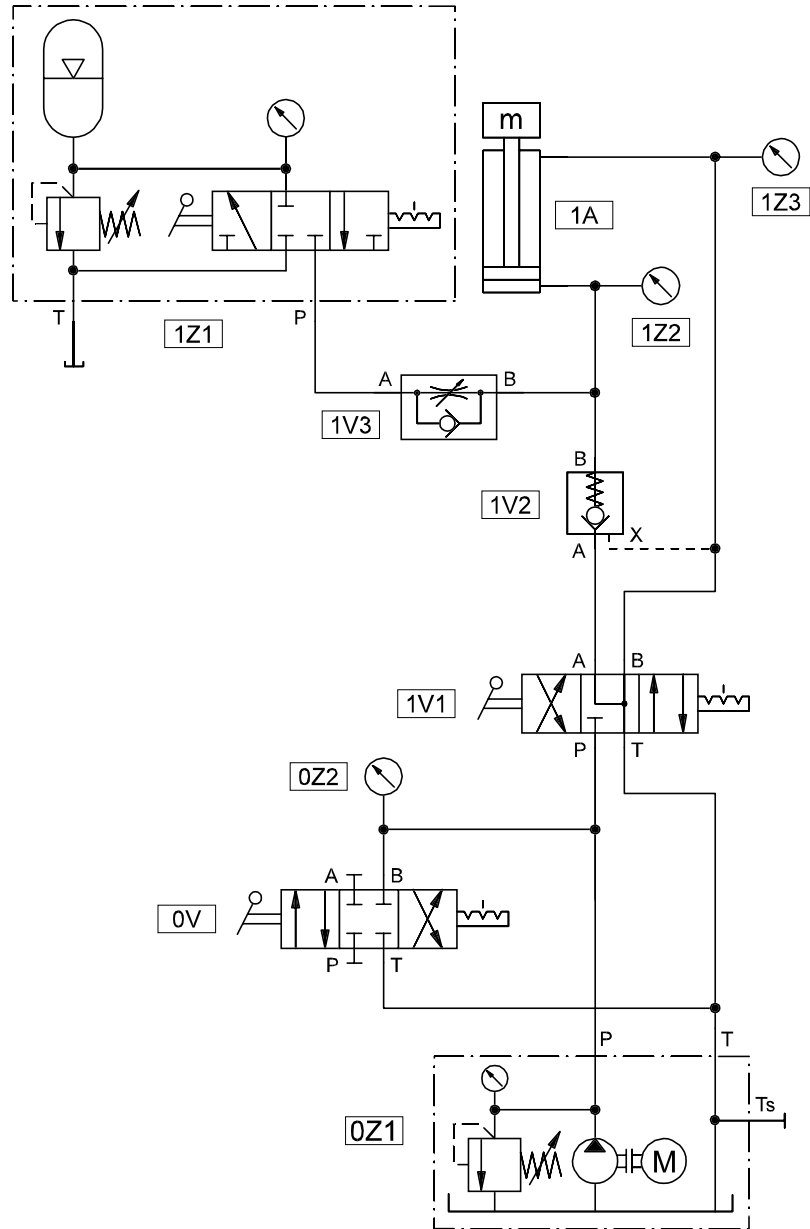| Item no.	Qty.	Description	
0Z1	1	Hydraulic power pack	*Components list*
0Z2, 1Z2, 1Z3	3	Pressure gauge	
0V	1	4/3-way hand-lever valve, closed in mid-position	
1V1	1	4/3-way hand-lever valve, relieved in mid-position	
1V2	1	Non-return valve, piloted	
1V3	1	One-way flow control valve	
1Z1	1	Diaphragm accumulator	
1A	1	Cylinder, double-acting	
	1	Weight	
	10	Hose line	
	4	Branch tee	

Assemble the circuit in accordance with the circuit diagram. Check that the 4/3-way hand-lever valve (1V1) used to reverse the cylinder is correctly connected up. The 2/2-way hand-lever valve to switch over to pump bypass is replaced by a 4/3-way hand-lever valve closed in its mid-position. This valve has detented positions to maintain the desired function. Once all the valves have been brought into their initial positions, the hydraulic power pack should be switched on. Furthermore, the clamping cylinder should be loaded with a weight in order to demonstrate its function.

Solution description

The one-way flow control valve should be opened by one scale division and the accumulator switched into the circuit. Operate the 4/3-way hand-lever valve (1V1) in such a way that the cylinder advances and the accumulator is charged. As soon as the piston reaches its forward end position, switch the valve to its mid-position. Despite being under load, the cylinder maintains its position. In order to relieve the pump, the valve (0V) should be reversed, thus creating a bypass circuit to the tank.

Reverse the 4/3-way hand-lever valve (1V1) again to initiate the return stroke of the cylinder. The accumulator will now be charged slowly via the one-way flow control valve.

Conclusions The pressure in the accumulator acts on the piston side of the cylinder. The non-return valve prevents the pressure from falling. The cylinder thus maintains its position despite the fact that the pump is relieved by a bypass circuit.

The non-return valve is opened to allow the cylinder to retract. This is achieved by applied system pressure to the pilot port X. Hydraulic fluid flows out of the piston chamber of the cylinder and out of the accumulator and back into the tank.

Note A circuit without a non-return valve and with a 4/3-way hand-lever valve with closed mid-position in place of the hand-lever valve (1V1) would also work. A pressure drop would occur over a period of time, however, since leakage oil within the 4/3-way valve would flow to the tank.
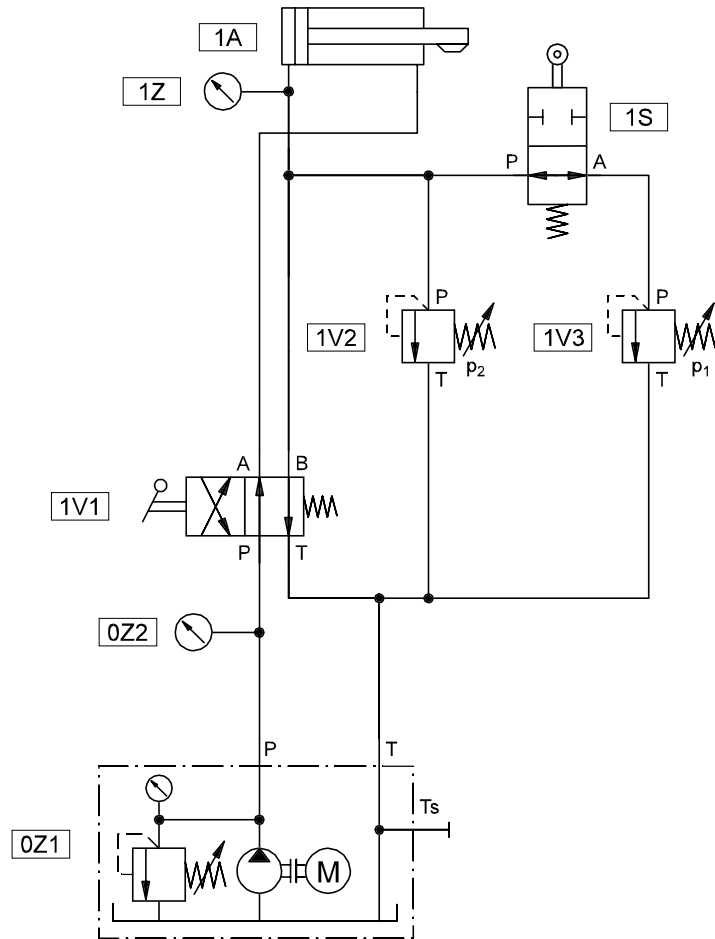
Plastic injection-moulding machine

Circuit diagram, hydraulic

Practical assembly,
hydraulic

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2, 1Z	2	Pressure gauge
1V1	1	4/2-way hand-lever valve
1V2, 1V3	2	Pressure relief valve
1S	1	2/2-way stem-actuated valve
1A	1	Cylinder, double-acting
	1	Mounting kit
	9	Hose line
	4	Branch tee

Components list

Once the hydraulic circuit has been assembled, the installation can be put into operation. The system pressure relief valve should be set to 60 bar. The cylinder is set in motion by operating the 4/2-way hand lever valve. The pressure on the piston side of the cylinder rises as a function of the piston position until the filling pressure p_1 or moulding pressure p_2 is reached.

Solution description

The stem-actuated valve should be removed from the circuit to allow the maximum filling pressure to be set on the pressure relief valve (1V3). The period during which the piston advances is too short to allow setting of the filling pressure.

Calculation of areas

Piston diameter: d_{PN} = 16 mm

Piston area

$$A_{PN} = \frac{\pi}{4} \cdot d_{PN}^2$$

$$A_{PN} = \frac{\pi}{4} \cdot 16^2 \text{ mm}^2 = 3.14 \cdot \frac{256}{4} \text{ mm}^2 = 3.14 \cdot 64 \text{ mm}^2 = 201 \text{ mm}^2$$

Calculation of pressures

Filling pressure for piston force $F_1 = 500$ N:

$$p_1 = \frac{F_1}{A_{PN}}$$

$$p_1 = \frac{500\,N}{201\,mm^2} \cdot \frac{10^6\,mm^2}{1\,m^2} = \frac{500 \cdot 10}{201} \cdot 10^5\,\frac{N}{m^2} = \frac{500 \cdot 10}{201}\,bar$$

$$p_1 = 24.9\,bar$$

Moulding pressure for piston force $F_2 = 1000$ N:

$$p_2 = \frac{F_2}{A_{PN}}$$

$$p_2 = \frac{1000\,N}{201\,mm^2} \cdot \frac{10^6\,mm^2}{1\,m^2} = \frac{1000 \cdot 10}{201} \cdot 10^5\,\frac{N}{m^2} = \frac{1000 \cdot 10}{201}\,bar$$

$$p_2 = 49.8\,bar$$

Evaluation		Piston force F (N)	Working pressure p (bar)
	1. Filling operation	500	24.9
	2. Moulding operation	1000	49.8

Conclusions When actuated, the 2/2-way stem-actuated valve switches off the pressure relief valve (1V3), which is set to a low pressure value. The working pressure thus rises one step, from filling pressure to moulding pressure.

Pressures are calculated as a function of the desired forces and set on the pressure relief valves.

Pipe-bending machine
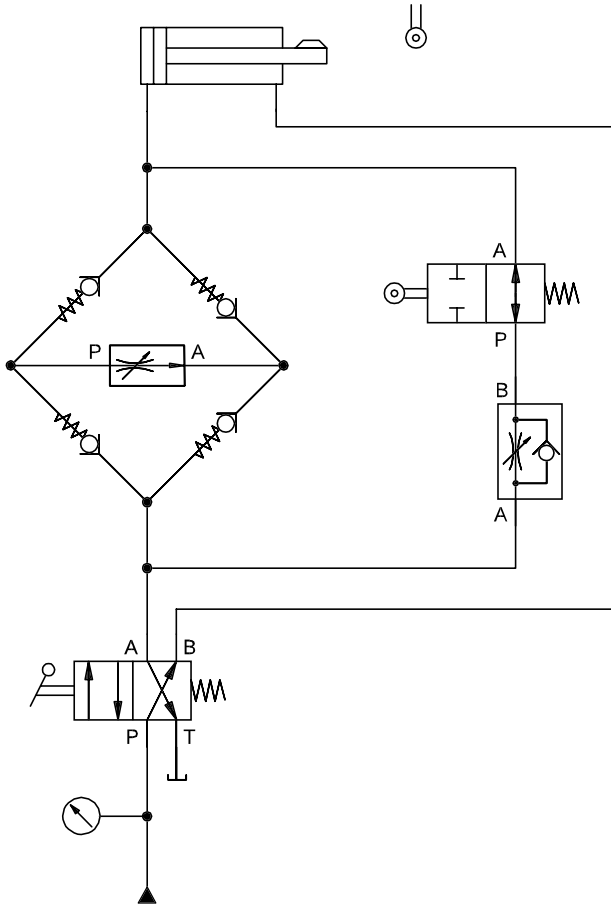
Circuit diagram, hydraulic

Practical assembly, hydraulic

1A

1S

1V5 1V6

1V4

P ⟶ A

1V7

B

A

1V2 1V3

A B

1V1

P T

0Z2

P T

Ts

0Z1

M

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2	1	Pressure gauge
1V1	1	4/2-way hand-lever valve
1V2, 1V3, 1V5, 1V6	4	Non-return valve
1V4	1	2-way flow control valve
1V7	1	One-way flow control valve
1S	1	2/2-way stem-actuated valve
1A	1	Cylinder, double-acting
	1	Mounting kit
	9	Hose line
	6	Branch tee
	1	Stop-watch

Components list

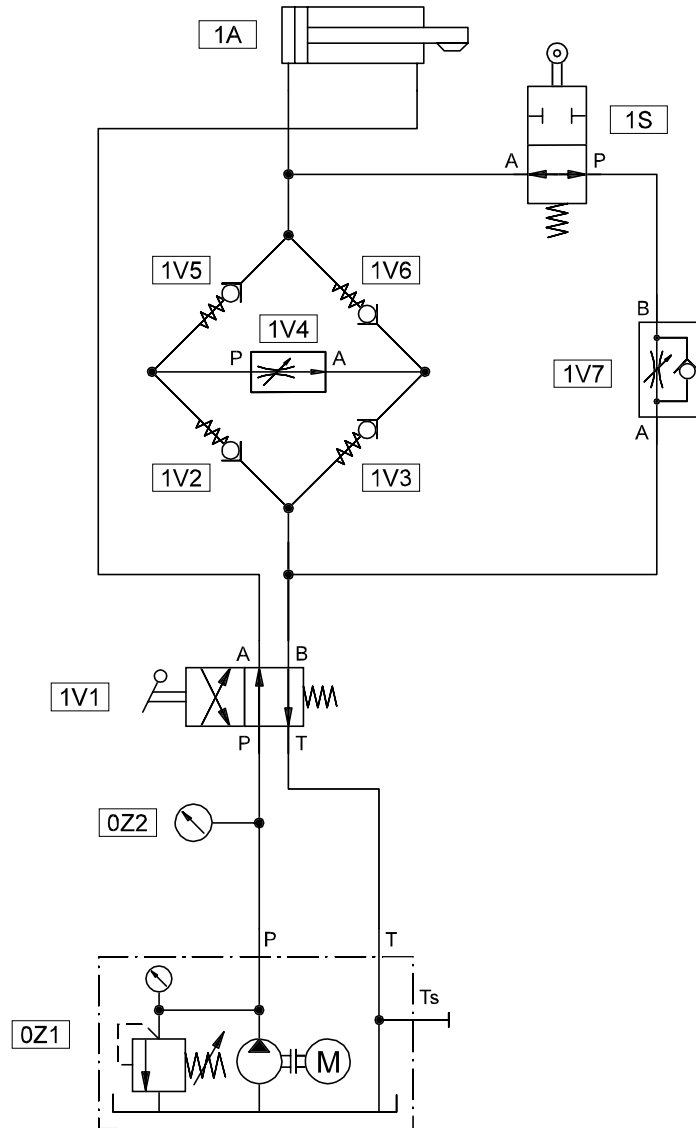Once the hydraulic circuit has been assembled, the installation can be put into operation. The system pressure relief valve should be set to 60 bar. The cylinder is set in motion by operating the 4/2-way hand lever valve.

Solution description

During the rapid-traverse motion, two part-streams flow via the 2-way flow control valve and the one-way flow control valve. As soon as the 2/2-way stem-actuated valve is actuated by the cam on the cylinder, one part-stream is shut off. The piston of the cylinder can now advance only at the feed speed set on the flow control valve.

	Rapid traverse for 150mm		Feed for 50mm		*Evaluation*
	Time t_1 (s)	v_1 (m/min)	Time t_2 (s)	v_2 (m/min)	
Advance stroke	1.0	9.0	3.0	1.0	
(Return stroke)	0.4	22.5	5.2	0.58	

Advance-stroke speed during rapid traverse

where s_1 = 150 mm, t_1 from value table:

$$v_1 = \frac{s_1}{t_1} = \frac{150 \text{ mm}}{1.0 \text{ s}} = \frac{0.15 \text{ m}}{1.0 \text{ s}} = 0.15 \frac{\text{m}}{\text{s}} \qquad 0.15 \frac{\text{m}}{\text{s}} \cdot \frac{60 \text{ s}}{1 \text{ min}} = 9 \frac{\text{m}}{\text{min}}$$

Advance-stroke speed during feed motion

where s_2 = 50 mm, t_2 from value table:

$$v_2 = \frac{s_2}{t_2} = \frac{50 \text{ mm}}{3.0 \text{ s}} = \frac{0.05 \text{ m}}{3.0 \text{ s}} = 0.167 \frac{\text{m}}{\text{s}} \qquad 0.167 \frac{\text{m}}{\text{s}} \cdot \frac{60 \text{ s}}{1 \text{ min}} = 1 \frac{\text{m}}{\text{min}}$$

Conclusions During the return stroke of the cylinder, hydraulic fluid also flows from P to A through the 2-way flow control valve. As soon as the stem-actuated valve is no longer actuated, the hydraulic fluid flows via the one-way flow control valve with no throttling effect.

The non-return valves of the rectifier circuit always feed hydraulic fluid to port P of the 2-way flow control valve, no matter where the flow of fluid originates. Depending on where the higher pressure is present, the appropriate non-return valve opens to allow flow to port P of the 2-way flow control valve. The non-return valve in the path to port A of the flow control valve is closed. From this point, hydraulic fluid can flow only via the unloaded non-return valve.

Single-column press
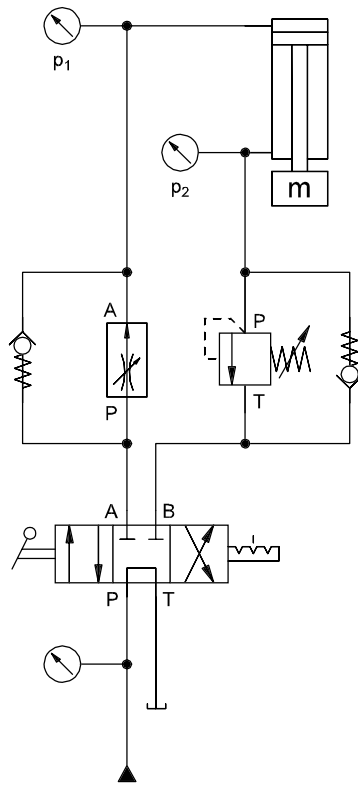
Practical assembly,
hydraulic

1Z1

1A

1Z2

m

1V2   1V3   1V4   1V5

1V1

0Z2

P   T

Ts

0Z1

M

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2, 1Z1, 1Z2,	3	Pressure gauge
1V1	1	4/3-way hand-lever valve with bypass position
1V2, 1V5	2	Non-return valve
1V3	1	2-way flow control valve
1V4	1	Pressure relief valve
1A	1	Cylinder, double-acting
	1	Weight
	8	Hose line
	4	Branch tee

Components list

Once the hydraulic circuit has been assembled, the 4/3-way hand-lever valve should be brought into its mid-position. Switch on the hydraulic power pack and close the system pressure relief valve until the pressure gauge shows 60 bar. The cylinder is set in motion by operating the 4/3-way hand lever valve.

Solution description

The effects on the various circuits on the motion of the cylinder can be observed if the 2-way flow control valve is opened only slightly (1½ turns).

Evaluation		*Pressure on piston side p1 (bar)*	*Pressure on annular piston side p2 (bar)*
	Circuit 1 with flow control valve in inlet	6	0
	Circuit 2 with flow control valve in outlet	58	80
	New circuit	58	60 or pressure setting

Conclusions Circuit 1 has no counter-holding. The visible effect of this is the irregular advance stroke of the cylinder, which is under tractive load. The 2-way flow control valve in the inlet to the piston side of the cylinder controls only the advance speed of the piston.

With circuit 2, excessive pressure is produced on the piston-rod side, due to the pressure-intensification effect in the cylinder. The 2-way flow control valve in the outlet from the piston-rod side of the cylinder provides a counter-holding function, and the cylinder advances evenly. However, the pressure in the piston-rod chamber rises excessively and is increased still further by the tractive load.

A pressure relief valve on the piston-rod side of the cylinder opposes the tractive load (counter-holding). The cylinder advances evenly. At the same time, excessive pressure is avoided, since the pressure relief valve opens to allow discharge to the tank as soon as the preset maximum pressure is exceeded. The best circuit is thus one which incorporates a flow control valve in the inlet line and a counter-holding function in the outlet line.
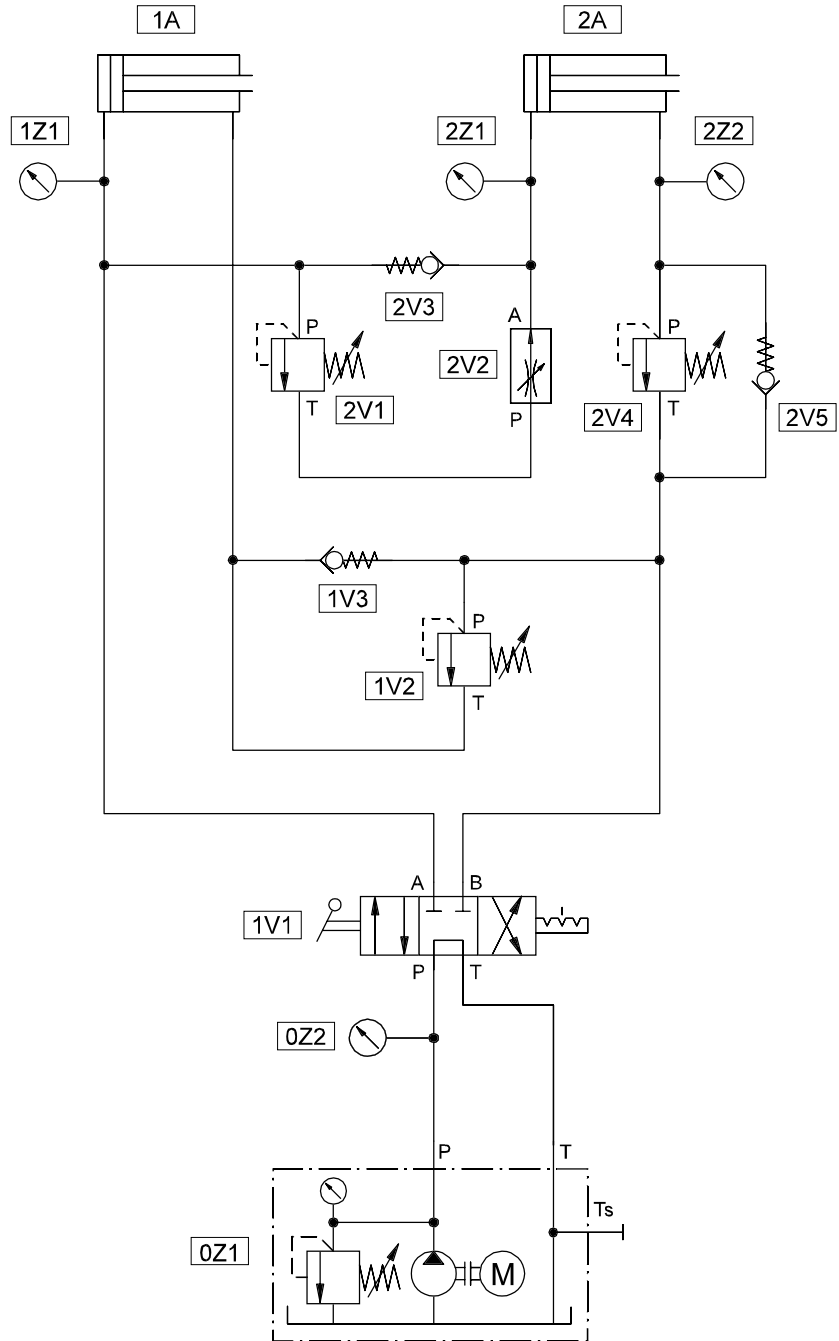
Machining centre
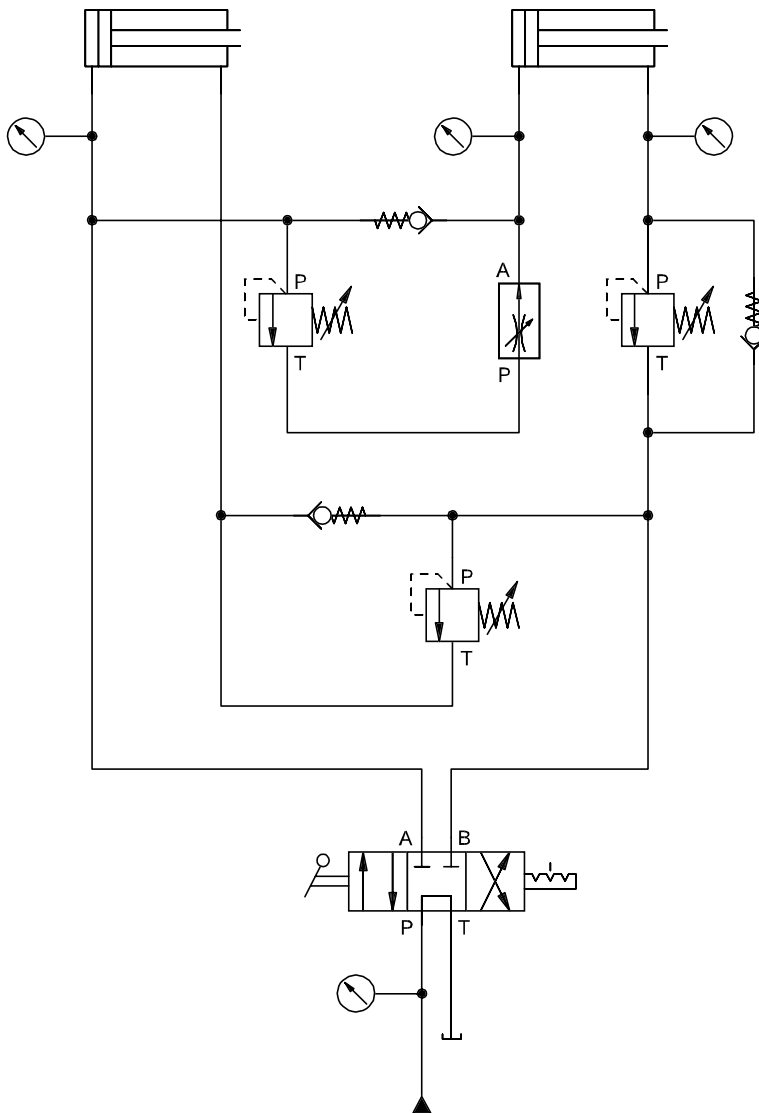
Practical assembly,
hydraulic

Item no.	Qty.	Description	
0Z1	1	Hydraulic power pack	*Components list*
0Z2, 1Z1, 2Z1, 2Z2	4	Pressure gauge	
1V1	1	4/3-way hand-lever valve with bypass position	
1V2, 2V1, 2V4	3	Pressure relief valve	
1V3, 2V3, 2V5	3	Non-return valve	
1A, 2A	2	Cylinder, double-acting	
2V2	1	2-way flow control valve	
	13	Hose line	
	8	Branch tee	

Once the hydraulic circuit has been assembled, the 4/3-way hand-lever valve should be brought into its mid-position. Switch on the hydraulic power pack and close the system pressure relief valve until the pressure gauge shows 60 bar. The machining centre is started by operating the 4/3-way hand lever valve to provide flow from P to A.
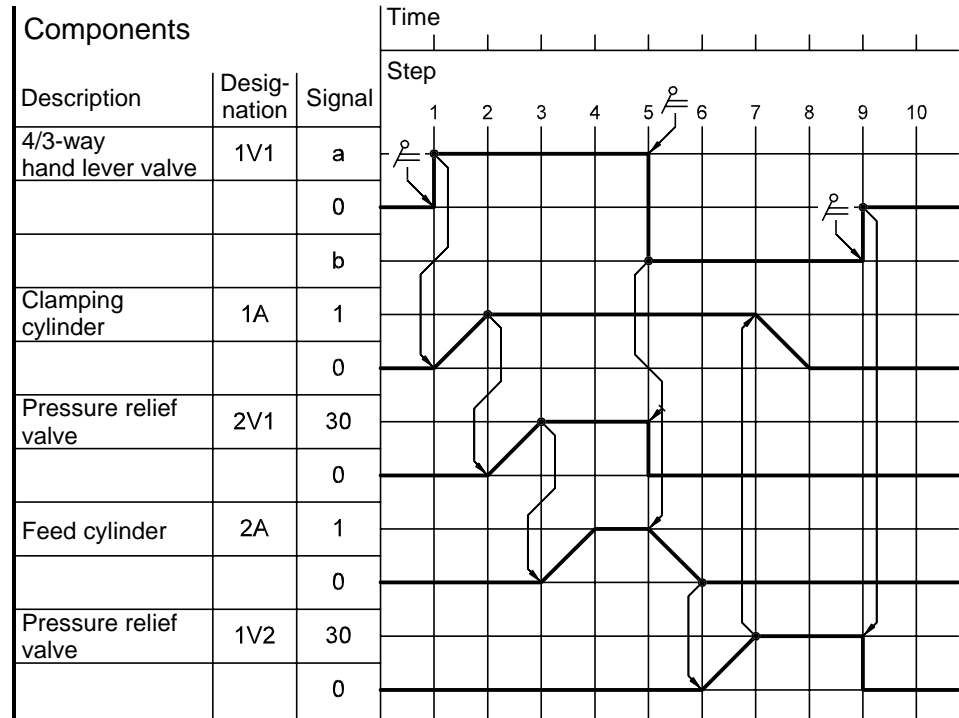
Solution description

With this sequence control, cylinder (1A) first advances and clamps the workpiece. Once the required clamping pressure has been reached, the pressure sequence valve (2V1) opens, allowing the feed cylinder (2A) to advance. The speed of this cylinder is adjusted by means of the flow control valve. The pressure relief valve (2V4) is used to provide counter-holding. As soon as the 4/3-way hand lever valve is switched to provide flow from P to B, the pressure sequence control is activated via the pressure sequence valve (1V2).

The time available to set the required clamping pressure is equal to the time taken by the feed cylinder to advance. To allow the clamping pressure to be set exactly to 30 bar, port T of the pressure sequence valve (2V1) should be connected to the tank of the hydraulic power pack. This requires an additional branch Tee at the tank connection. The pressure for the return stroke of the clamping cylinder should be set in a similar way.

Displacement/step diagram

Components			Time
Description	Desig-nation	Signal	Step
4/3-way hand lever valve	1V1	a	
		0	
		b	
Clamping cylinder	1A	1	
		0	
Pressure relief valve	2V1	30	
		0	
Feed cylinder	2A	1	
		0	
Pressure relief valve	1V2	30	
		0	

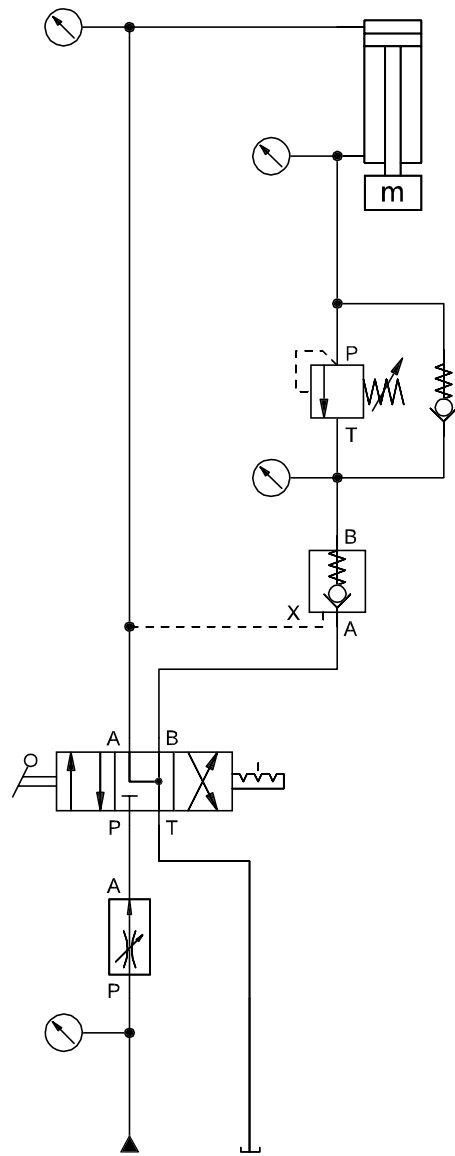*Conclusions* A pressure relief valve is used as a pressure sequence valve. As soon as the preset maximum pressure is reached, the pressure relief valve opens to allow flow to the tank connection.

The feed cylinder follows the clamping cylinder. The feed cylinder starts to move when the pressure in the clamping cylinder exceeds the maximum value set on the pressure sequence valve.
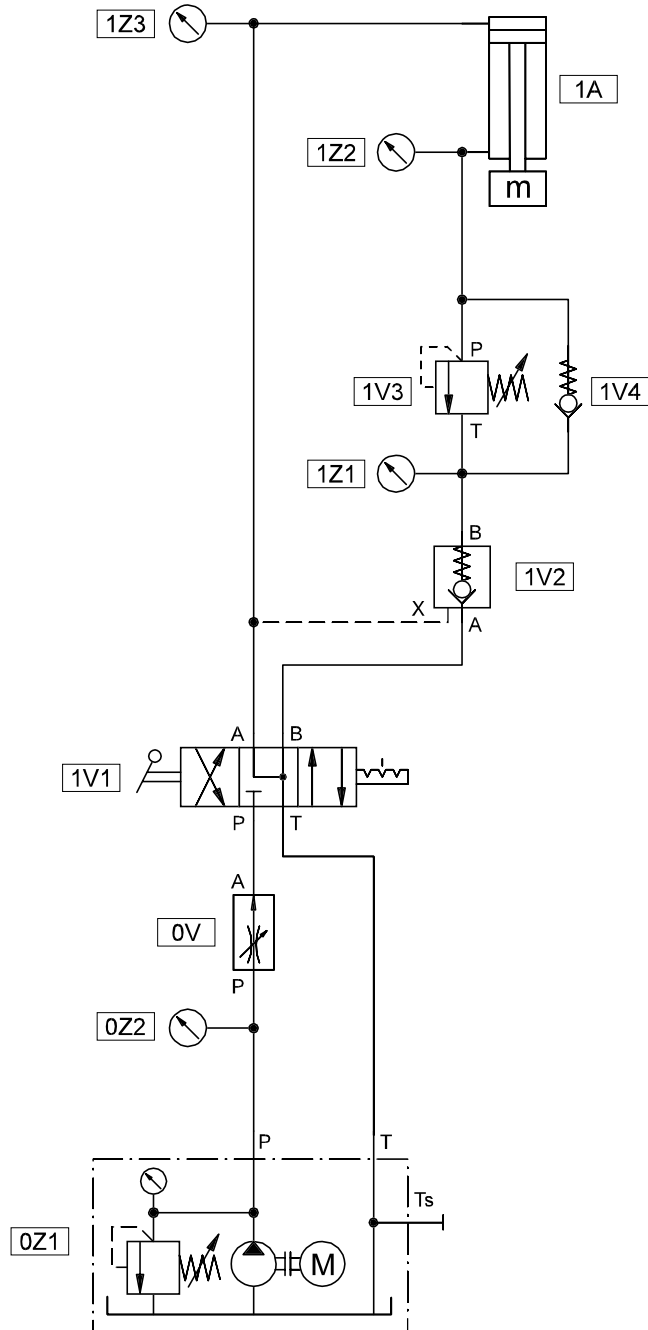
Magnetic crane

Solution 11

Practical assembly,
hydraulic

1Z3

1A

1Z2

m

P

1V3   WM   1V4

T

1Z1

B

1V2

X

A

A   B

1V1

P   T

A

0V

P

0Z2

P   T

Ts

0Z1   M

Item no.	Qty.	Description	
0Z1	1	Hydraulic power pack	*Components list*
0Z2, 1Z1, 1Z2, 1Z3	4	Pressure gauge	
0V	1	2-way flow control valve	
1V1	1	4/3-way hand-lever valve, relieved in mid-position	
1V2	1	Non-return valve, piloted	
1V3	1	Pressure relief valve	
1V4	1	Non-return valve	
1A	1	Cylinder, double-acting	
	1	Weight	
	9	Hose line	
	3	Branch tee	

Assemble the circuit in accordance with the circuit diagram. Check that the 4/3-way hand-lever valve (1V1) used to reverse the cylinder is correctly connected up. Once all the valves have been brought into their initial positions, switch on the hydraulic power pack. The cylinder is set in motion by operating the 4/3-way hand lever valve.
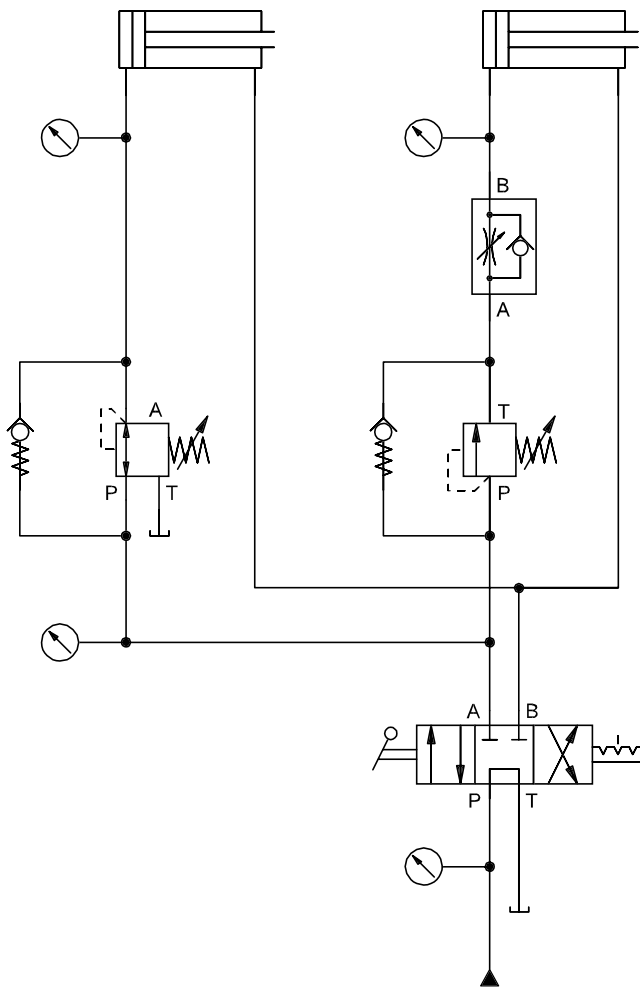
Solution description

Use the 2-way flow control valve to reduce the flow rate until the cylinder advances in approx. 10 seconds. Note that the cylinder advances in an uncontrolled way without counter-holding. With a counter-pressure of approx. 3 bar or more, an even cylinder advance speed is obtained. The required counter-pressure is relatively low, since on the one hand the load is small and on the other the resistances in the return lines are high.

Conclusions   The piloted non-return valve holds the cylinder in position. The tractive load acting on the cylinder causes the non-return valve to close, and as a result the piston cannot advance any further. The cylinder position will thus be maintained even in the case of hydraulic system pressure failure.

As soon as the pilot port of the piloted non-return valve is pressurised, the cylinder can advance. The pressure at the pilot port of the non-return valve enables flow from B to A. Hydraulic fluid from the piston-rod chamber of the cylinder flows via the pressure relief valve and the non-return valve to the tank.
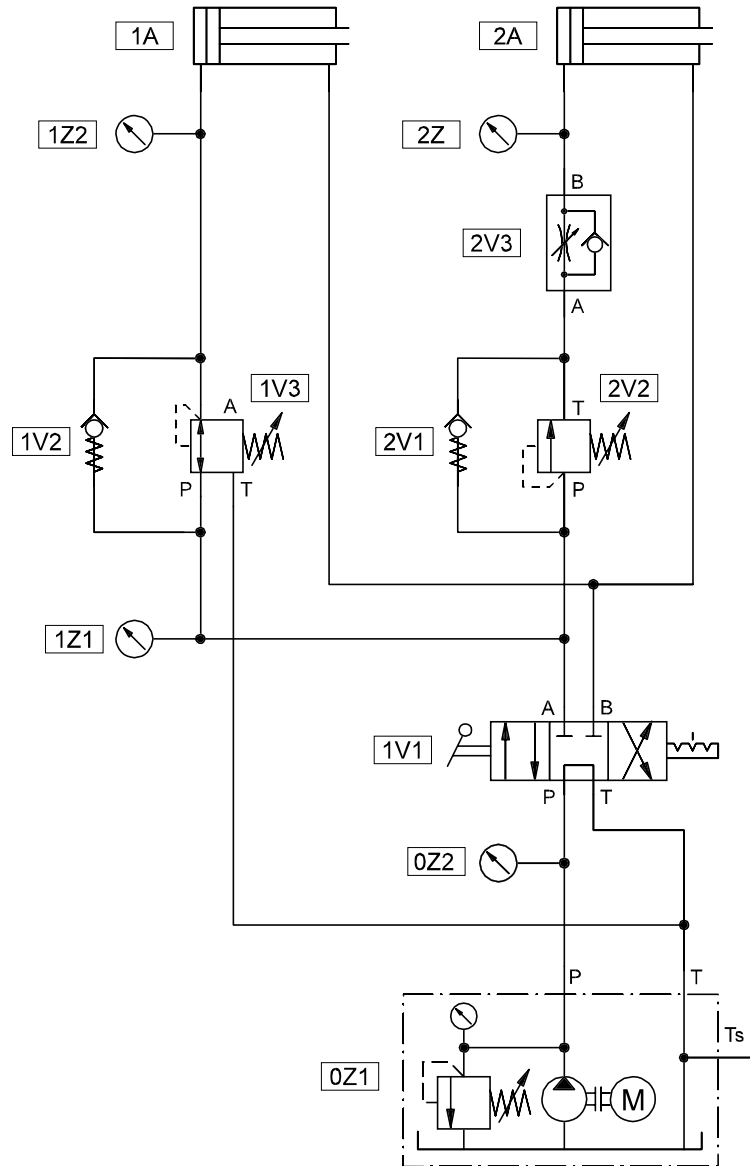
Folding machine

Practical assembly,
hydraulic

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2, 1Z1, 1Z2, 2Z	4	Pressure gauge
1V1	1	4/3-way hand-lever valve with bypass position
1V2, 2V1	2	Non-return valve
1V3	1	Pressure regulator
1A, 2A	2	Cylinder, double-acting
2V2	1	Pressure relief valve
2V3	1	One-way flow control valve
	11	Hose line
	7	Branch tee

Components list

Once the hydraulic circuit has been assembled, the 4/3-way hand-lever valve should be brought into its mid-position. Switch on the hydraulic power pack and close the system pressure relief valve until the pressure gauge shows 60 bar. The cylinders are set in motion by operating the 4/3-way hand lever valve to provide flow from P to A.

*Solution description*

First, cylinder (1A) advances and clamps the workpiece. Once the required clamping pressure has been reached, the pressure upstream of the pressure sequence valve (2V2) rises. As soon as the preset maximum pressure is reached, the pressure sequence valve opens and the feed cylinder (2A) can advance. The speed of this cylinder is adjusted by means of the one-way flow control valve.

Weg-Schritt-Diagramm

Components			Time
Description	Desig-nation	Signal	Step
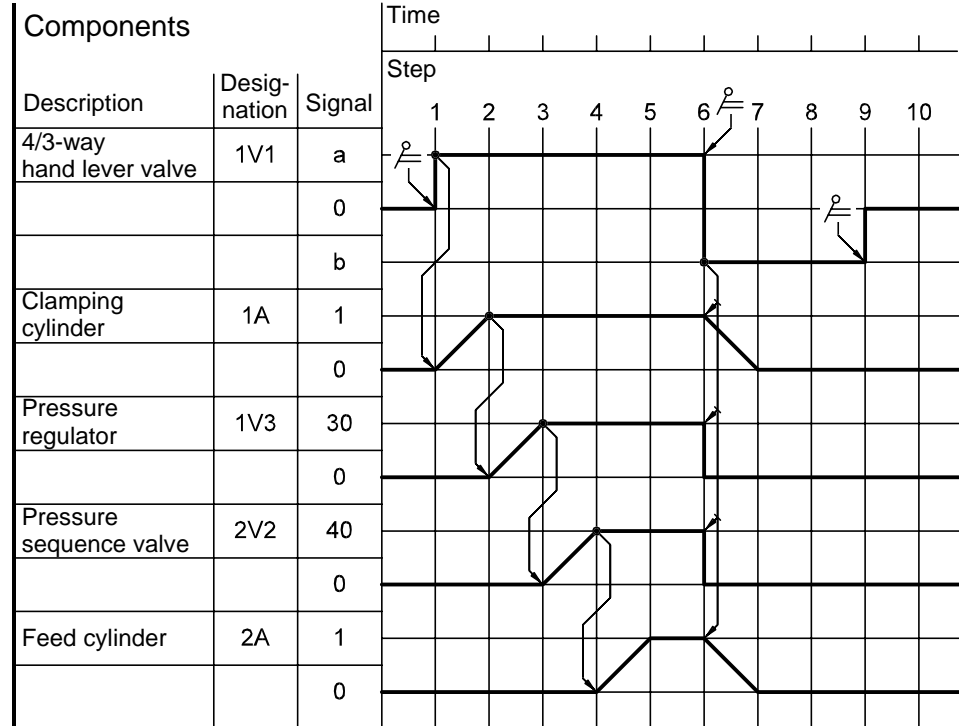
Calculation of area

Piston diameter: d_{PN} = 16 mm

Piston area

$$A_{PN} = \frac{\pi}{4} \cdot d_{PN}^2$$

$$A_{PN} = \frac{\pi}{4} \cdot 16^2 \text{ mm}^2 = 3.14 \cdot \frac{256}{4} \text{ mm}^2 = 3.14 \cdot 64 \text{ mm}^2 = 201 \text{ mm}^2$$

Calculation of pressure

Clamping pressure for piston force F= 600 N

$$p = \frac{F}{A_{PN}}$$

$$p = \frac{600\,N}{201\,mm^2} \cdot \frac{10^6\,mm^2}{1\,m^2} = \frac{600 \cdot 10}{201} \cdot 10^5\,\frac{N}{m^2} = \frac{600 \cdot 10}{201}\,bar$$

$p \approx 30\ bar$

The 3-way pressure regulator can be used to set the pressure for the clamping force as appropriate to the workpiece. Soft materials can be clamped with lower force and machined. The system pressure upstream of the pressure regulator can be used for a second control chain.
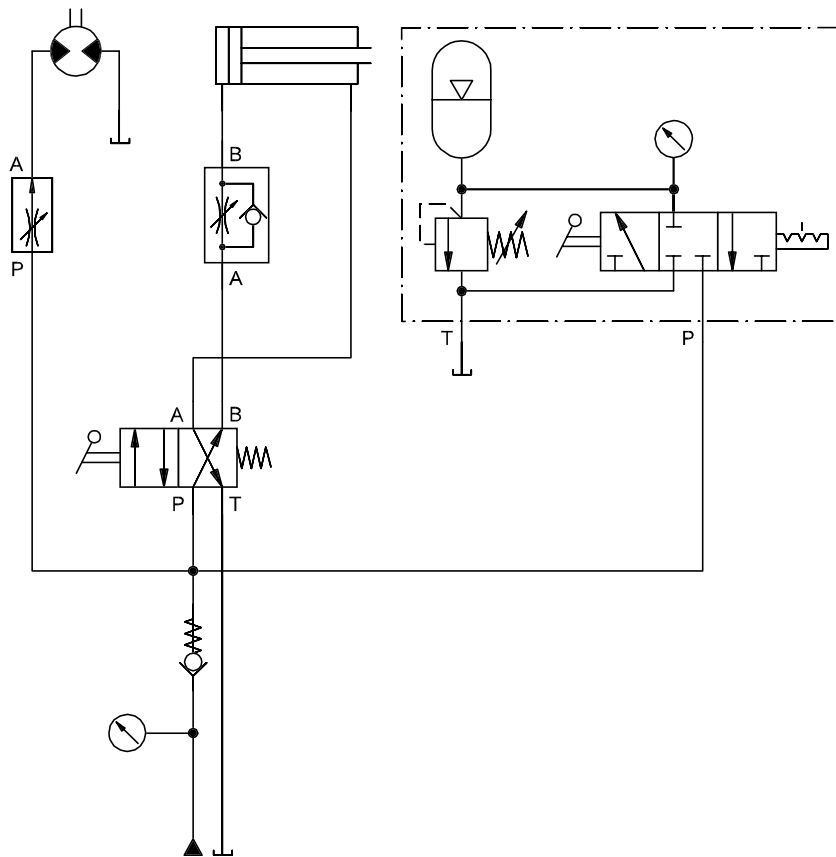
Conclusions

A pressure rise at the valve outlet causes the path from B to T to open. This case would occur if an excessive bending force acted on the clamping cylinder. This would, however, indicate that the clamping pressure had not been matched to the workpiece material.

Earth drill

Circuit diagram, hydraulic

*Practical assembly,
hydraulic*

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2	1	Pressure gauge
0Z3	1	Diaphragm accumulator
0V	1	Non-return valve (1bar)
1V	1	2-way flow control valve
1A	1	Hydraulic motor
2V1	1	4/2-way hand-lever valve
2V2	1	One-way flow control valve
2A	1	Cylinder, double-acting
	11	Hose line
	7	Branch tee
	1	Stop-watch

Once the hydraulic circuit has been assembled, the installation can be put into operation. The system pressure relief valve should be set to 60 bar. The actuators are set in motion by operating the 4/2-way hand lever valve.

Solution description

The cylinder must advance slowly to ensure that sufficient time is available to charge the accumulator. It is advisable to open the one-way flow control valve by ½ scale division. The flow control valve used to control the speed of the hydraulic motor should also be opened only slightly (2 turns) to ensure that sufficient fluid is available for the accumulator.

In order to measure the return-stroke times, the accumulator can be activated and deactivated by means of the hand lever of the built-in shut-off valve.

Evaluation	Return stroke without accumulator		Return stroke with accumulator	
	Time for 1stroke t_0 *(s)*	*Speed* v_0 *(m/min)*	*Time for 1stroke* t_1 *(s)*	*Speed* v_1 *(m/min)*
	1.2	10.0	0.4	34.3

Calculation of speeds

Return-stroke speed without diaphragm accumulator:

$$v_0 = \frac{s}{t_0} \qquad \text{with } s = 200 \text{ mm}$$

$$v_0 = \frac{s}{t_0} = \frac{200 \text{ mm}}{1{,}2 \text{ s}} = \frac{0.2 \text{ m}}{1.2 \text{ s}} = 0.167 \frac{\text{m}}{\text{s}} \cdot \frac{60 \text{ s}}{1 \text{ min}} \approx 10 \frac{\text{m}}{\text{min}}$$

Return-stroke speed with diaphragm accumulator:

$$v_1 = \frac{s}{t_1} \qquad \text{with } s = 200 \text{ mm}$$

$$v_1 = \frac{s}{t_1} = \frac{200 \text{ mm}}{0.4 \text{ s}} = \frac{0.2 \text{ m}}{0.4 \text{ s}} = 0.5 \frac{\text{m}}{\text{s}} \cdot \frac{60 \text{ s}}{1 \text{ min}} \approx 30 \frac{\text{m}}{\text{min}}$$

Speed difference:

$$\Delta v = v_1 - v_0 = 30 \frac{\text{m}}{\text{min}} - 10 \frac{\text{m}}{\text{min}} = 20 \frac{\text{m}}{\text{min}}$$

Calculation of volumes

Hydraulic power pack: Max. delivery in period t_1

$$V_{P,t_1} = q_P \cdot t_1 \quad \text{with} \quad q_P = 2.2 \frac{l}{\text{min}} = 2.2 \frac{\text{dm}^3}{\text{min}} = 2200 \frac{\text{cm}^3}{\text{min}}$$

$$V_{P,t_1} = 2200 \frac{\text{cm}^3}{\text{min}} \cdot 0.4 \text{ s} = 2200 \frac{\text{cm}^3}{60\text{s}} \cdot 0.4 \text{ s}$$

$$V_{P,t_1} \approx 14.7 \text{ cm}^3$$

Cylinder: Volume in piston-rod chamber

$$V_Z = A_{AN} \cdot s \quad \text{with } A_{AN} = 122.5 \text{ mm}^2 \quad \text{and } s = 200 \text{ mm}$$

$$V_Z = 122.5 \text{ mm}^2 \cdot 200 \text{ mm} = 24500 \text{ mm}^3 = 24.5 \text{ cm}^3$$

Volumetric difference z to be supplied by accumulator in period t_1

$$\Delta V = V_Z - V_{P,t_1} = 24.5 \text{ cm}^3 - 14.7 \text{ cm}^3 = 9.8 \text{ cm}^3$$

The accumulator allows the return-stroke speed of the cylinder to be increased significantly. The measured return-stroke times indicate a cylinder return-stroke speed of 10 m/min. without an accumulator and 30 m/min. with an accumulator. This means that the peak demand for hydraulic fluid during the rapid-traverse motion is met by the accumulator. The pump delivery need be calculated only for average consumption.

Conclusions

Machining centre

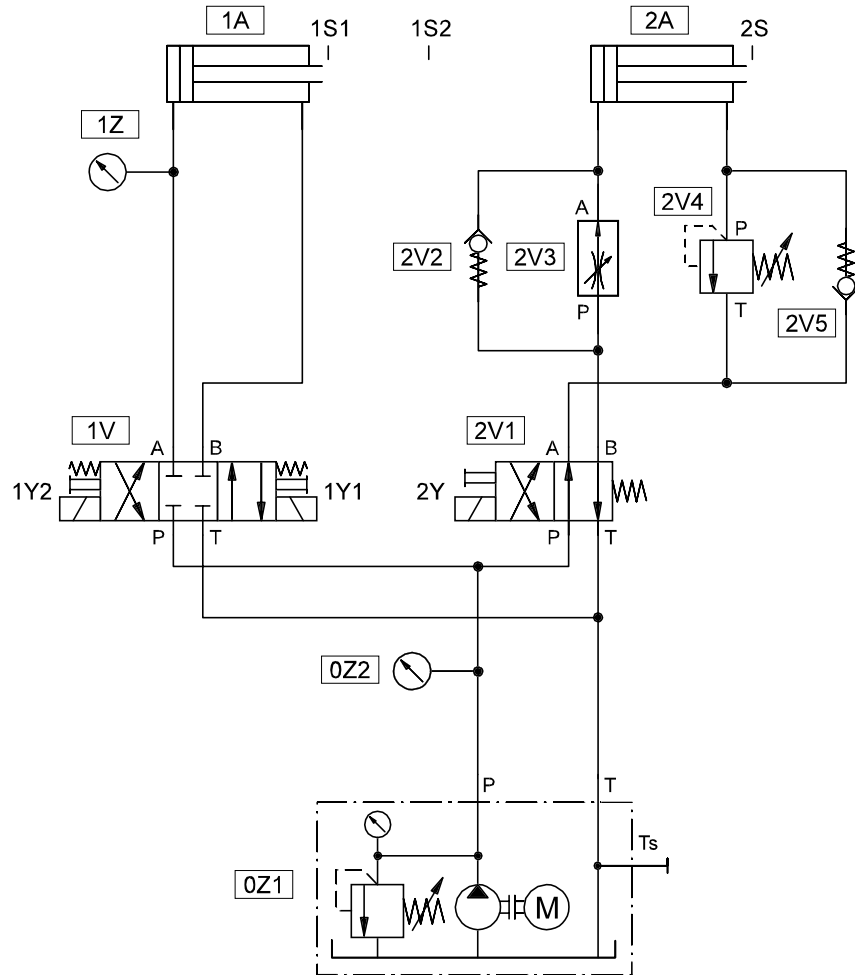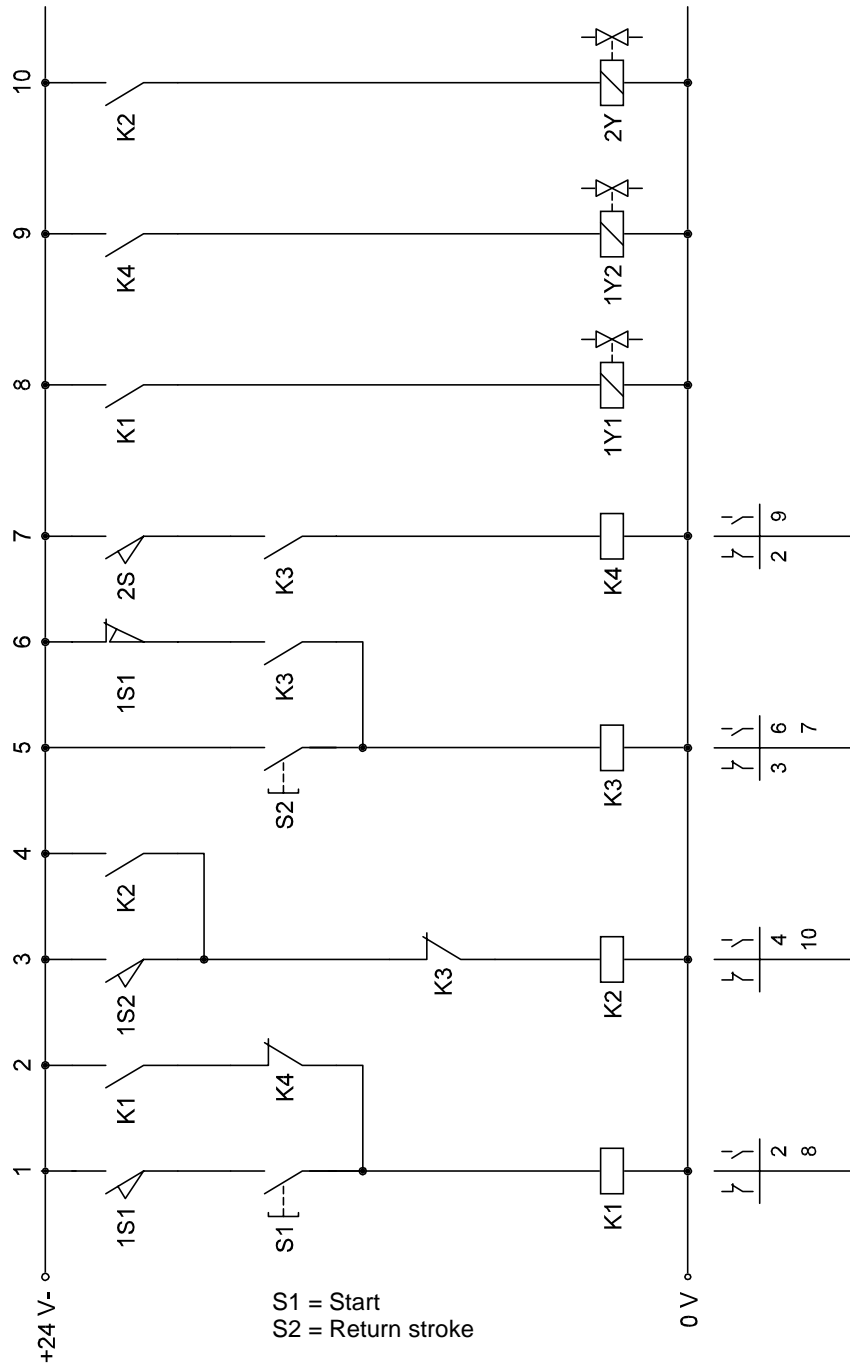1S1   1S2   2S

1Y1   1Y2   2Y
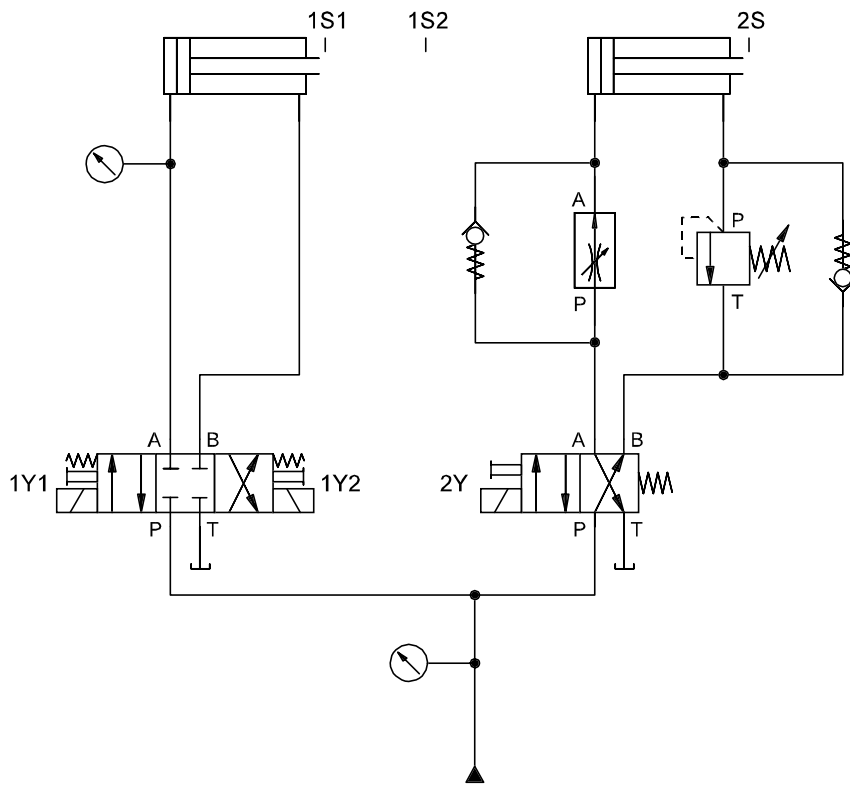
Practical assembly,
hydraulic

Circuit diagram, electrical

S1 = Start
S2 = Return stroke

Components list,
hydraulic

Item no.	Qty.	Description
0Z1	1	Hydraulic power pack
0Z2, 1Z	2	Pressure gauge
1V	1	4/3-way solenoid valve, closed in mid-position
1A, 2A	2	Cylinder, double-acting
2V1	1	4/2-way solenoid valve
2V2, 2V5	2	Non-return valve
2V3	1	2-way flow control valve
2V4	1	Pressure relief valve
	12	Hose line
	6	Branch tee

Components list,
electrical

Item no.	Qty.	Description
	3	Limit switch
	1	Signal input unit
	2	Relay, 3-fold
	1	Cable set
	1	Power supply unit

Displacement/step diagram
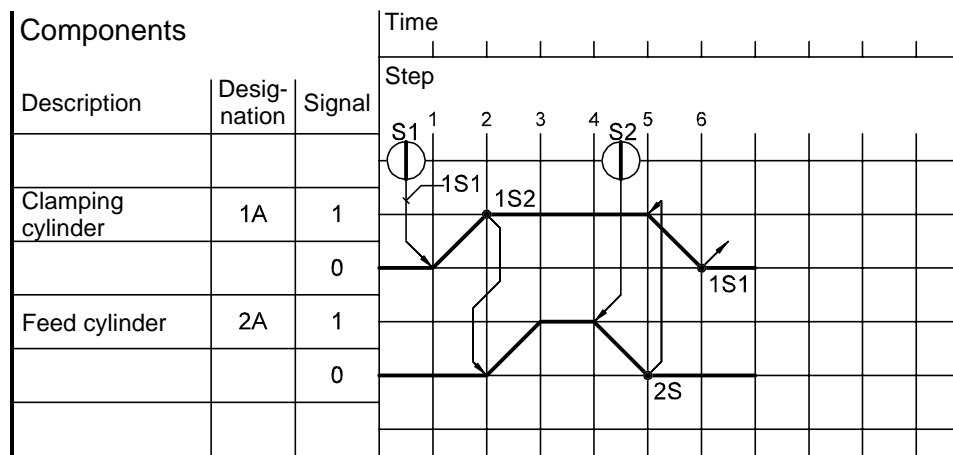
Assemble the circuit in accordance with the circuit diagram. Check that, when the 4/2-way solenoid valve is in its normal position, the feed cylinder remains in the retracted end position. Switch on the hydraulic power pack and close the system pressure relief valve until the pressure gauge shows 60 bar. The valves can now be switched by connecting the relays to a 24 V supply to check hydraulic operation. Ensure when assembling the electrical circuit that each relay switches under the specified conditions.

Solution description

Advance stroke:
Provided that the limit switch (1S1) is actuated, the relay (K1) will latch via current path 2 when the "Start" pushbutton (S1) is pressed. The relay contacts of K1 switch the 4/3-way solenoid valve to flow from P to A (1Y1). The piston rod of the clamping cylinder (1A) advances to its forward end position, where it actuates the limit switch (1S2) and activates current path 3. The relay (K2) reverses and latches via current path 4. The 4/2-way solenoid valve (2Y) is pressurised and the feed cylinder advances under flow control and with counter-holding. The limit switch (2S), which has been actuated up to now, is released.

Return stroke:
The switch (S2) is used to activate the relay (K3), which latches via current path 5. The switch acts as a normally-closed contact in current path 3 to interrupt the latching of the relay (K2). The 4/2-way solenoid valve (1Y2) assumes its normal position and the feed cylinder retracts. As soon as the feed cylinder has reached the retracted end position, the relay (K4) is activated by the limit switch (2S) via current path 7. This relay in turn interrupts the latching of the relay (K1) via current path 2. The solenoid (1Y1) of the 4/3-way solenoid valve is de-activated, while simultaneously the solenoid (1Y2) is activated. The clamping cylinder retracts. As soon as this has reached the retracted end position, the limit switch (1S1) is actuated. This interrupts the latching of relay (K3), in turn de-activating relay (K4). All relays are now in their normal position and a new working cycle can be started.

Conclusions The installation can be started with the pushbutton (S1) only when the limit switch (1S1) is actuated (start condition). This ensures that the installation is in its initial position.

No matter what stage has been reached in the working cycle, the relay (K2) is de-activated when the switch (S2) is actuated. The feed cylinder then immediately retracts if it is not already in the retracted end position. When the limit switch (2S) is actuated in this position, this fulfils the second condition for the retraction of the clamping cylinder. Switch (S2) has priority. As long as this is actuated, the relays for the advance stroke of the cylinder cannot be activated.