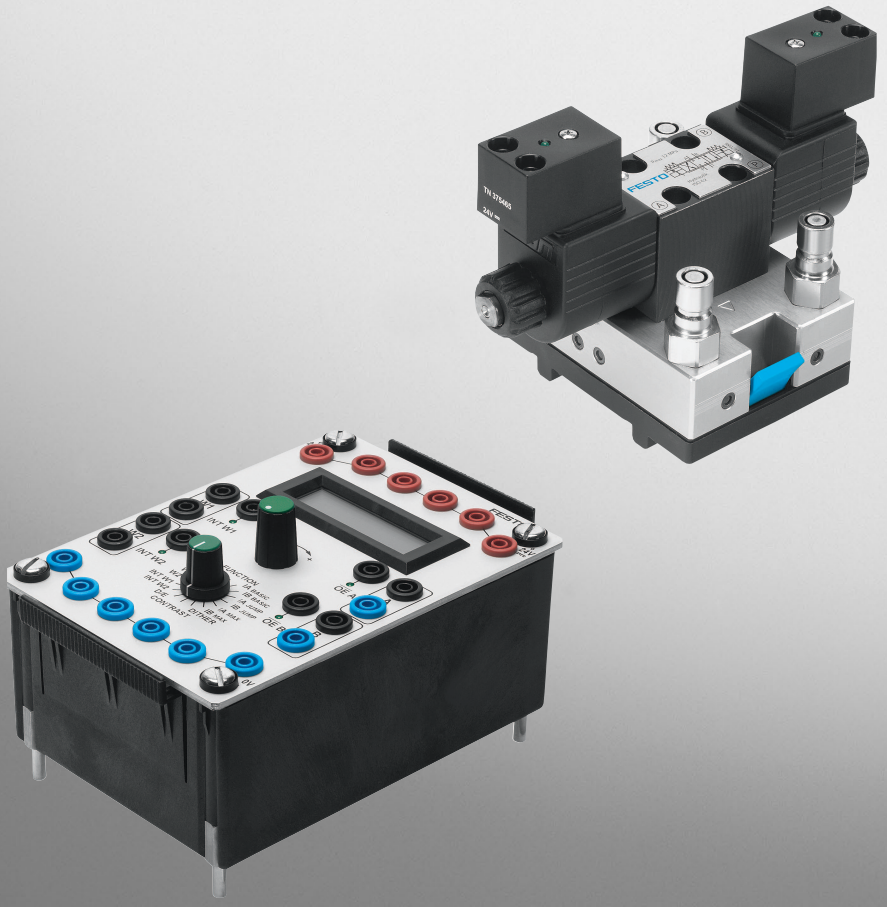
Proportional hydraulics
Basic level

FESTO

Workbook
TP 701

With CD-ROM



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Order No.: 094472
Edition: 02/2004
Layout: 02.2004, OCKER Ingenieurbüro
Graphics: OCKER Ingenieurbüro
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Preface

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

- Basic Packages provide fundamental knowledge which is not limited to a specific technology.
- Technology Packages deal with the 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).

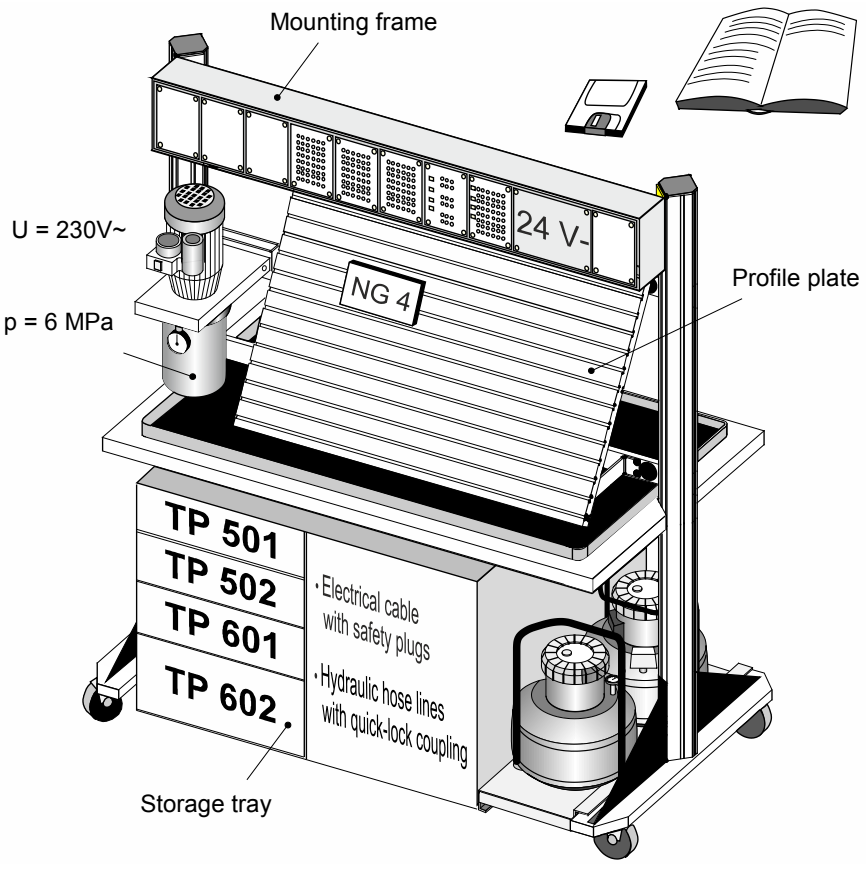

Fig. 1:
Example of Hydraulics 2000: Mobile laboratory trolley

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, electronic transparencies for PCs 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, CAD programs, 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 Proportionalhydraulics TP701.

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 datasheets

Table of contents

Section A – Course

Section B - Fundamentals

Section C - Solutions

Section D - Appendix

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Introduction

This workbook forms part of Festo Didactic's Learning System for Automation and Communications. TP700 is intended as an introduc-tion to the fundamentals of proportional hydraulics and consists of a basic level and advanced level. The basic level TP701 provides the basic knowledge on proportional hydraulics, which is consolidated and dealt with in greater depth in the advanced level TP702.

The following points have been included in the design concept of the hydraulic components:

- Simple handling
- Secure attachment
- Environmentally friendly coupling technology
- Compact components
- Practice-oriented measuring technology

The following are recommended for the practical implementation of the exercises:

- Hydraulic and electrical components of equipment set TP701
- A hydraulic power pack
- Several hoses
- A power supply unit
- A set of cables
- A slotted profile plate or corresponding laboratory equipment
- A measuring set with the necessary sensors

The aim of this workbook is to familiarise the student with equipment and basic circuits of proportional hydraulics. The exercises deal with the following subjects:

- Plotting of characteristic curves of individual components and valves
- Use of components and valves
- Construction of different basic circuits
- Optimum harmonisation of components by means of setting parameter

The technical prerequisites for the safe operation of components are:

- A hydraulic power pack for an operating pressure of 60 bar and volumetric flow rate of 2 l/min
- A supply voltage of 230 V AC for the power pack
- A power supply unit with 24 V DC for the electrical components
- A Festo Didactic slotted profile plate for the attachment of components

This workbook has been developed for use in the “Dual system” of vocational training. It is, however, equally suitable for use in providing a practical introduction to electrohydraulics for students at universities and technical colleges. The modular design of the hardware allows theoretical questions to be dealt with experimentally in a simple and efficient form.

The theoretical correlations are explained in Section B - Fundamentals.

The technical description of the components used can be found in the data sheets in section D of this workbook.

The following additional training material for hydraulics is also available from Festo Didactic:

- Magnetic symbols
- Hydraulic slide calculator
- Sets of overhead transparencies
- Sets of transparent models
- Interactive video
- Symbols library
- Simulation program

Safety recommendations

The following safety advice should be observed in the interest of your own safety:

- Caution! Cylinders may advance as soon as the hydraulic power pack is switched on!
- Do not exceed the permitted working pressure (see data sheets).
- Use only extra-low voltages of up to 24 V.
- Observe general safety regulations (DIN58126 and VDE100).

Notes on procedure

Construction

The following steps are to be observed when constructing a control circuit.

1. The hydraulic power pack and the electrical power supply unit must be switched off during the construction of the circuit.
2. All components must be securely attached to the slotted profile plate i.e. safely latched and securely mounted.
3. Please check that all return lines are connected and all hoses securely connected.
4. Make sure that all cable connections have been established and that all plugs are securely plugged in.
5. First, switch on the electrical power supply unit and then the hydraulic power pack.
6. Make sure that the hydraulic components are pressure relieved prior to dismantling the circuit, since:

   Couplings must be connected unpressurised!

7. First, switch off the hydraulic power pack and then the electrical power supply unit.

Technical notes

The following notes are to be observed in order to ensure trouble-free operation.

- An adjustable pressure relief valve has been integrated in the hydraulic power pack Pt. No. 152962. For reasons of safety, the sys-tem pressure has been limited to approx. 6 MPa (60 bar).
- The maximum permissible pressure for all hydraulic components is 12 MPa (120 bar).

The working pressure is to be at a maximum of 6 MPa (60 bar).

- In the case of double-acting cylinders, an increase in pressure may occur according to the area ratio as a result of pressure transference. With an area ratio of 1:1.7 and an operating pressure of 6 MPa (60 bar) this may be in excess of 10 MPa (100 bar)!

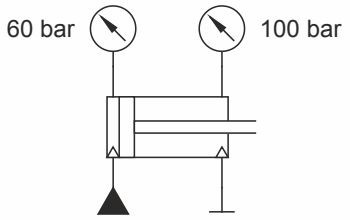


Fig. 2:
Pressure transference

- If the connections are released under pressure, pressure is locked into the valve or device via the non-return valve in the coupling (see Fig. 3). This pressure can be reduced by means of pressure relieving device Pt. No. 152971. Exception: This is not possible in the case of hoses and non-return valves.
- All valves, equipment and hoses have self-sealing couplings. These prevent inadvertent oil spillage. For the sake of simplicity, these couplings have not been represented in the circuit diagrams.

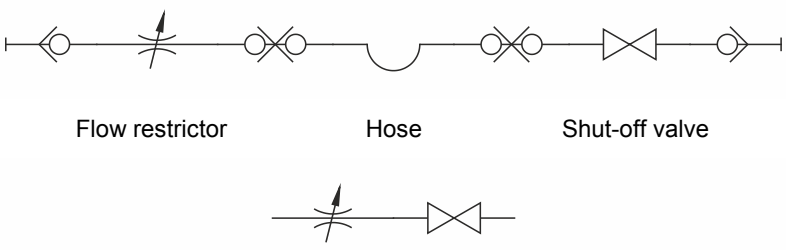


Fig. 3:
Symbolic representation of sealing couplings

The flow sensor

The flow sensor consists of:

- a hydraulic motor, which converts the volumetric flow rate q into a speed n,
- a tachometer, which supplies a voltage V proportional to the rotational speed n,
- a universal display, which converts the voltage V into the flow rate q in l/min, which is set at sensor No. 3 on the universal display.

Fig. 4: Block diagram

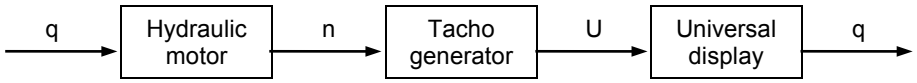


Fig. 5: Circuit diagrams, hydraulic and electrical

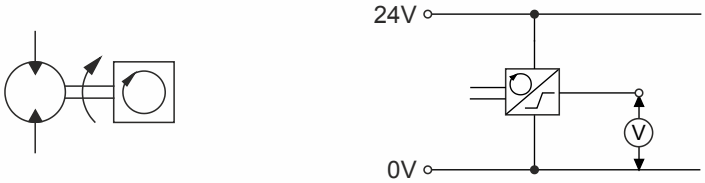
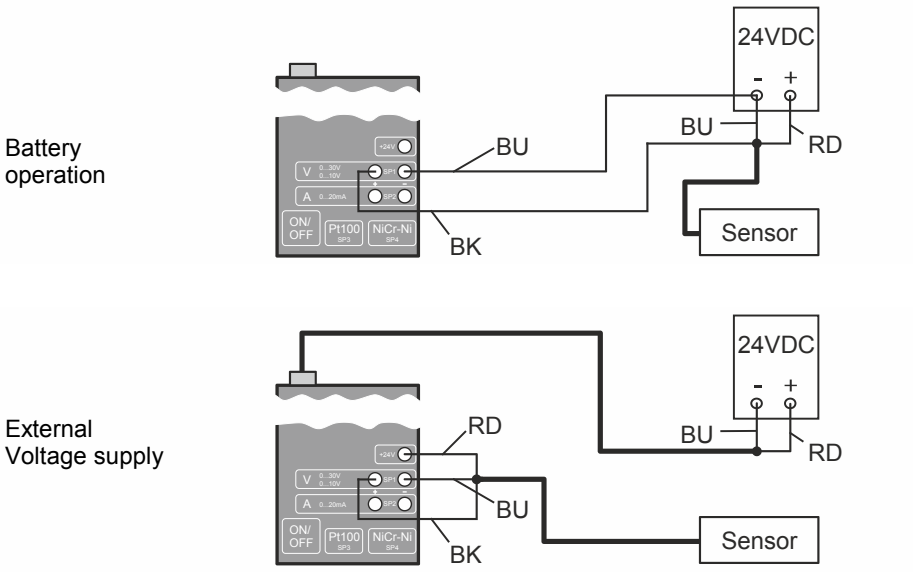


Fig. 6: Connection of universal display



Setting of setpoint values and amplifier card

Actuation of a proportional valve requires a setpoint value card and an amplifier card. The setpoint value card specifies voltages in the form of setpoint values. The amplifier card converts these into control currents for the valve solenoids. Both cards are set by means of a selector switch and a rotary knob. The menu and the set values are shown in the display. Different logic operations of the set values have been designated depending on the application. This is why the basic setting should be checked prior to commissioning. The following settings are recommended:

Setpoint value card:

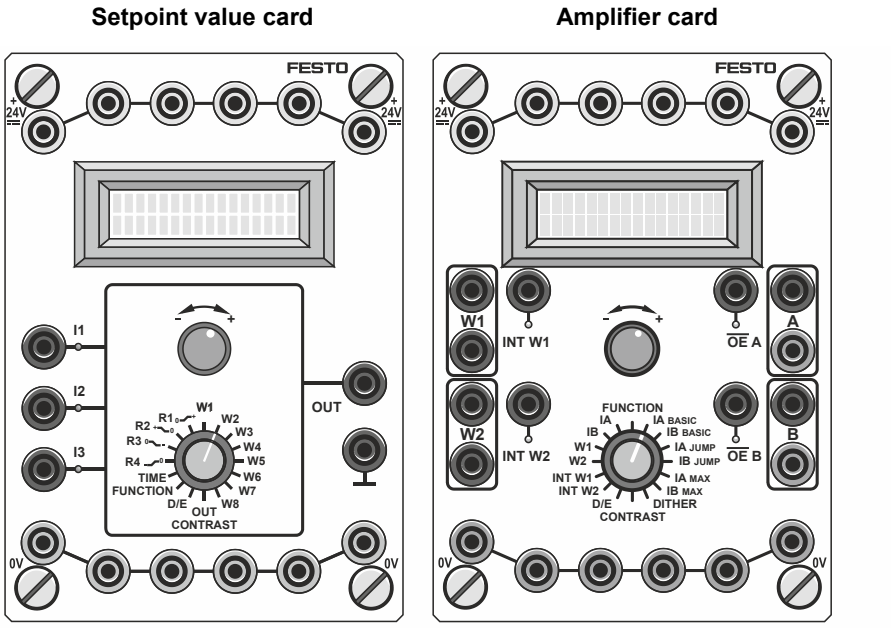
- FUNCTION at “Internal selection”.
- Advance switching time TIME at approx. 1 s.
- All ramps R1 to R4 at Zero.
- All setpoint values W1 to W8 at Zero.
- Inputs I1 to I3 and output not allocated.

Amplifier card:

- FUNCTION at “Two-channel amplifier ”.
- IA BASIC to IB JUMP currents approx. 10 mA.
- IA MAX and IB MAX currents at 1000 mA.
- Dither frequency at approx. 250 Hz.
- Internal setpoint values INT W1 and INT W2 at Zero.
- Inputs W1 and W2 and outputs A and B not allocated.

- All other settings depend on the application and corresponding advice is given in the examples. A description of the functions is comprised in the data sheets in section D.

Fig. 7: Setpoint value and amplifier card



Training contents of proportional hydraulics

Section A *Basic level TP701*

- Establishing characteristic curves and parameters of valves and components
- Harmonisation of electrical and hydraulic devices
- Measuring of variables such as pressure, volumetric flow rate and time
- Control of pressure and speed
- Reading and drawing up of hydraulic and electrical circuit diagrams
- Creating a function diagram
- Application of symbols according to DIN/ISO 1219
- Design and commissioning of controllers including fault finding
- Optimisation of settings for individual applications
- Basic circuits of proportional hydraulics such as pressure stage circuit, rapid traverse feed circuit, pump by-pass, approaching of positions, controlled acceleration and deceleration, logic operations of setpoint values, load-independent speeds

Section B

- Design and function of different proportional valves
- Characteristics and parameters of proportional valves
- Design and function of amplifier and setpoint value specification
- Flow calculation for proportional directional control valves
- Calculation of velocities of double-acting cylinders with different loads
- Calculation of natural frequency of a cylinder drive
- Calculation of acceleration and deceleration times

List of training aims of the exercises

Exercises	*Training aims*
1	Familiarisation with the characteristic curve of a single-channel amplifier. To be able to set the basic current.
2	Familiarisation with the characteristic curves of a proportional pressure relief valve. To be able to fully set a single-channel amplifier.
3	Familiarisation with a pressure stage control system.
4	Familiarisation with the characteristic curve of a two-channel amplifier. To be able to set the basic current, jump current and maximum current.
5	Familiarisation with the characteristic curves of a 4/3-way proportional valve. To establish the setting of a two-channel amplifier.
6	To decelerate the advancing of a cylinder. To set a ramp.
7	To reverse a hydraulic motor. To derive ramp settings from the function diagram.
8	To set process-oriented pressure stages. To logically connect the setpoint values externally.
9	To approach a position with deceleration.
10	To establish a load-independent feed rate.

Equipment set for Basic Level TP701

Description	*Order No.*	*Quantity*
Pressure gauge	152841	2
Flow restrictor	152842	1
One-way flow control valve	152843	1
Branch tee	152847	2
Pressure relief valve, pressure sequence valve	152848	1
Double-acting cylinder, 16/10/200	152857	1
Hydraulic motor, 8 l/min	152858	1
Pressure filter	152969	1
Weight , 9 kg	152972	1
Pressure balance	159351	1
Relay plate, 3 fold	162241	1
Signal input, electrical	162242	1
Proportional amplifier, 2 channel	162255	1
Setpoint value card	162256	1
4/2-way solenoid valve	167082	1
4/3-way proportional valve	167086	1
Proportional pressure relief valve	167087	1
Proximity sensor, inductive	178574	2

Basic Level TP701, Order No. 184465

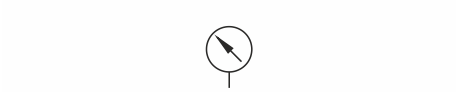
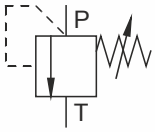
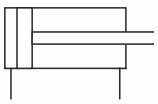
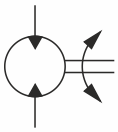
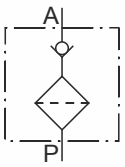
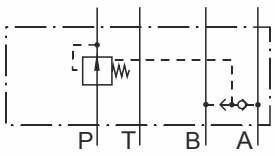
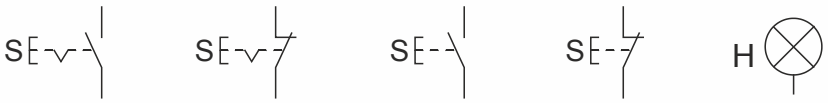
Additional components

Description	*Order No.*	*Quantity*
Oscilloscope	152917	(1)
Cable, BNC/4mm	152919	(2)
Universal display	183737	1
Pressure sensor	184133	(1)
Flow sensor	152858	1

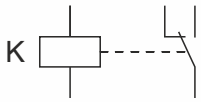
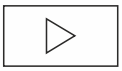
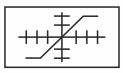
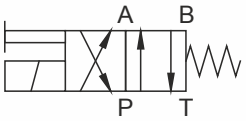
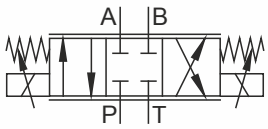
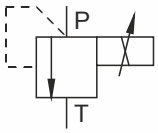
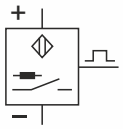
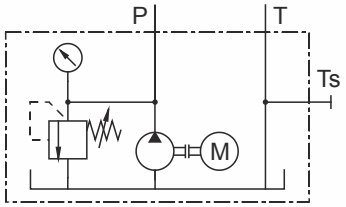
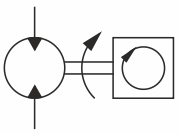
Accessories

Description	*Order No.*	*Quantity*
Set of cables with safety plugs	167091	1
Power supply unit, 24 V	162417	1
Hose, 600 mm	152960	5
Hydraulic power pack, 2 l/min	152962	1
Pressure relieving device	152971	1
Protective cover	152973	1
Hose, 1500 mm	159386	2

Symbols of equipment set TP701

Pressure gauge 	Flow restrictor 
One-way flow control valve 	Branch tee 
Pressure relief valve, pressure sequence valve 	Double-acting cylinder 16/10/200 
Hydraulic motor, 8 l/min 	Pressure filter 
Weight, 9 kg 	Pressure balance 
Signal input, electrical 	

Symbols of equipment set TP701

Relay, 3 fold 	Proportional amplifier 
Setpoint value card 	4/2-way solenoid valve 
4/3-way proportional valve 	Proportional pressure relief valve 
Proximity sensor, inductive 	Hydraulic power pack (full) 
Hydraulic power pack (simplified) 	Flow sensor 
Hydraulic motor with tachometer generator 	Hose 

Allocation of components and exercises

	Exercises									
Components	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Relay plate, 3 fold,			1				1	1	1	
Signal input, electrical,			1				1	1	1	
Proportional pressure relief valve	1	1	1					1		
Setpoint value card,	1	1	1	1	1	1	1	1	1	1
Proportional amplifier	1	1	1	1	1	1	1	1	1	1
Pressure gauge		1	1		2	2	2	2	2	3
Flow restrictor		1								
One-way flow control valve								1		
Branch tee			2		2			2		
Pressure relief valve					1					
4/2-way solenoid valve			1					1		
Cylinder			1			1		1	1	1
Hydraulic motor		(1)			(1)		1			
Proximity sensor, inductive								2	1	
Pressure filter		1	1		1	1	1	1	1	1
Weight										1
Pressure balance										1
4/3-way proportional valve				1	1	1	1		1	1
Set of cables	1	1	1	1	1	1	1	1	1	1
Power supply unit	1	1	1	1	1	1	1	1	1	1
Stop watch										1
Oscilloscope						(1)				(1)
Cable, BNC/4mm						(2)				(2)
Hydraulic power pack		1	1		1	1	1	1	1	1
Hose 600		2	5		4	3	3	5	3	3
Hose 1500		2	2		2	2	2	2	2	2
Universal display		1			1					
Pressure sensor						(1)				(1)
Flow sensor		1			1					

Methodological structure of exercises

The workbook is structured in the form of exercises in section A and solutions to exercises in section C. The methodolical structure is identical for all exercises.

- The exercises in **section A** are divided into:
  - Subject
  - Title
  - Training aim
  - Problem definition
  - Problem description
  - Positional sketch

This is followed by the worksheet for the practical implementation of the exercise using:

  - Block diagrams
  - Symbols for circuit diagrams
  - Setting aids
  - Evaluation aids such as value tables for measured values, coordinates for characteristic curves
  - Revision

- The solutions in **section C** contain:
  - Hydraulic circuit diagram
  - Electrical circuit diagram
  - Table of settings
  - Solution description with evaluation and conclusion
  - Circuit diagram, hydraulic
  - Circuit diagram, electrical
  - Components list, hydraulic
  - Components list, electrical
  - Conclusion

- How should I work through an exercise?
  - Read the worksheet
  - Complete the worksheet
  - Assemble and commission the control circuit
  - Work out your own solution
  - Compare your solution with the one in this book
  - Incorporate your solution into the control circuit
  - Commission this circuit
  - Does your control circuit fulfil the requirements specified in the worksheet?

Part A – Course

Proportional hydraulics — *Subject*

Embossing press — *Title*

Training aims

- Familiarisation with the characteristic curve of a single-channel amplifier
- To be able to set the basic current, jump current and maximum current

Problem definition

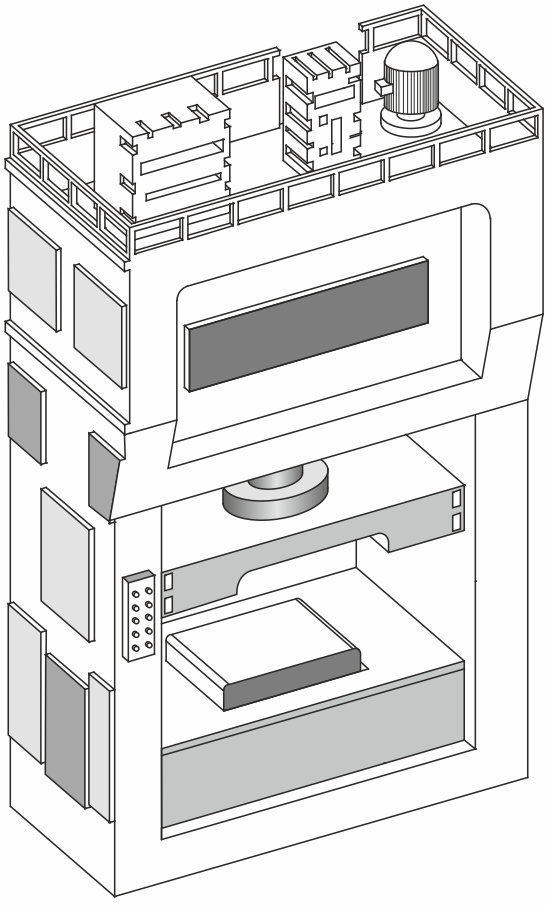
- Drawing the electrical circuit diagram
- Constructing the circuit
- Setting the setpoint value
- Setting the basic current, jump current and maximum current
- Plotting the characteristic curve of the single-channel amplifie

Problem description

An embossing press is to be used to form metal parts, whereby the specified working pressure is to be maintained. The stamp of the embossing press is to be actuated via a hydraulic cylinder. The working pressure is to be set by means of a proportional pressure relief valve, which is actuated via a proportional amplifier.

The size of metal parts are found to be inconsistent. In order to establish the cause of this error, first of all the functioning of the proportional amplifier is to be checked. The characteristic curve is to be recorded for this purpose.

Fig. 1/1: Positional sketch



WORKSHEET

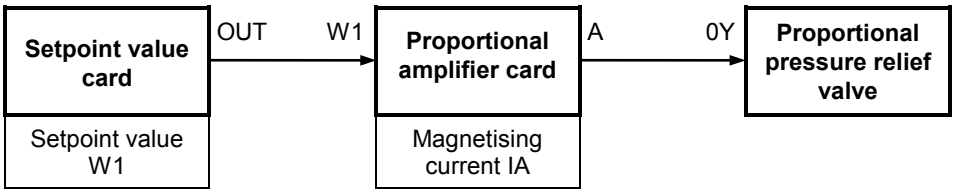


Fig. 1/2: Block diagram

Fig. 1/3: Circuit diagram, electrical

Setting Setpoint value card

Selector switch	*Display*
FUNCTION	Select setpoint values with E1, E2, E3
W1	Setpoint value: W1 = 2.7 V

So long as E1 = E2 = E3 = 0 applies, W1 is the valid setpoint value.

Setting Amplifier card

Selector switch	*Display*
FUNCTION	Two 1-channel amplifiers
IA BASIC	Basic current A: IA basic = 0.0 mA
IA JUMP	Jump current A: IA jump = 0.0 mA
IA MAX	Maximum current A: IA max = 1000 mA
IA	Output current A: IA = 270 mA

WORKSHEET

W1 = Setpoint value 1
IA = Current of amplifier A

Evaluation

W1 (V)	0.0	2.0	4.0	6.0	8.0	10.0
IA (mA)						

Value table 1

IA BASIC = 200 mA
IA JUMP = 0.0 mA
IA MAX = 800 mA

W1 (V)	0.0	5.0	10.0
IA (mA)			

Value table 2

IA BASIC = 200 mA
IA JUMP = 100 mA
IA MAX = 800 mA

W1 (V)	0.0	0.1	5.0	10.0
IA (mA)				

Value table 3

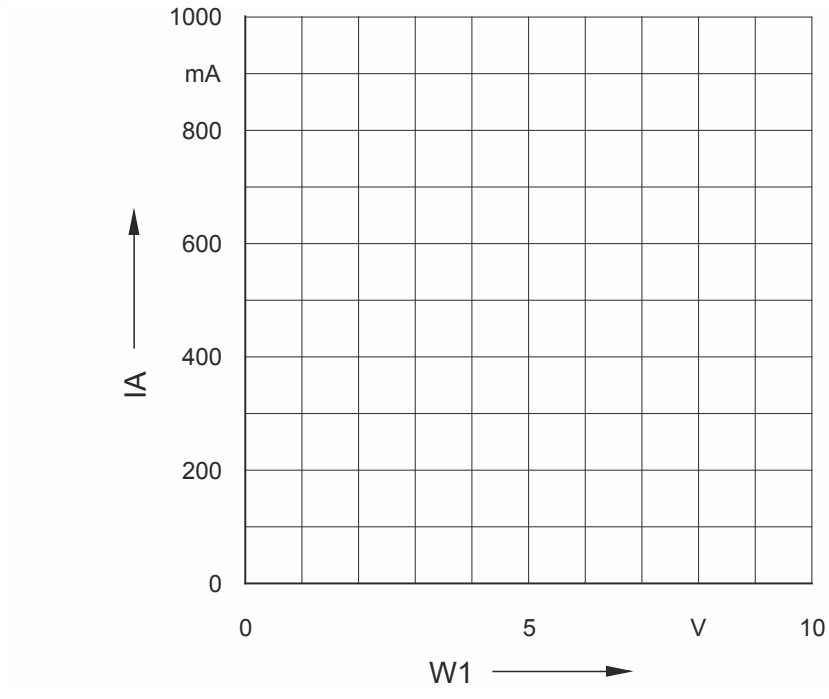


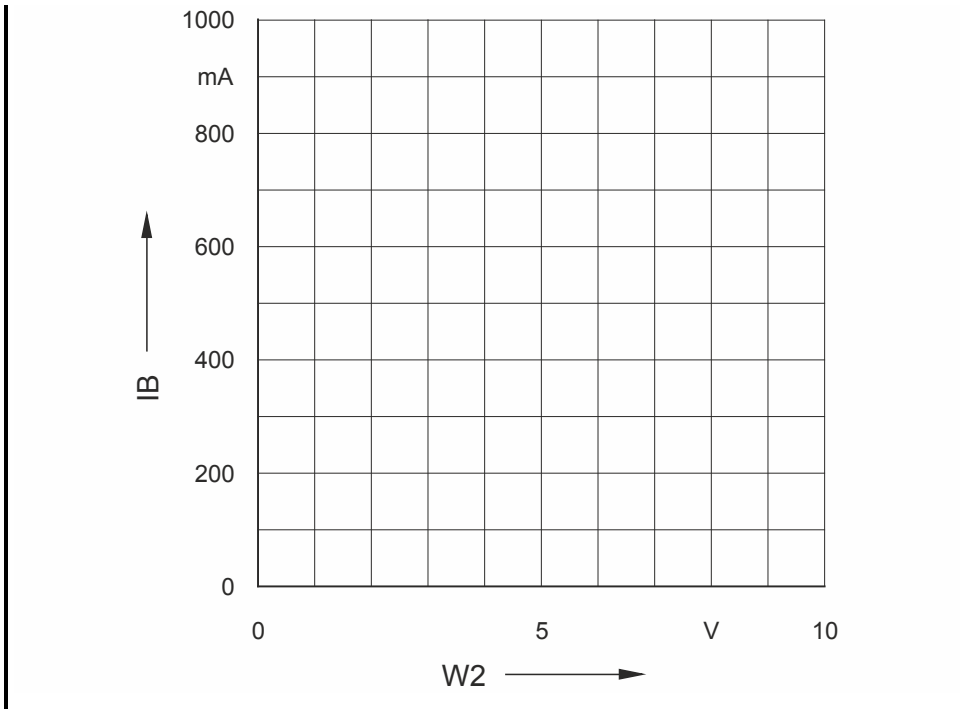
Fig. 1/4:
Characteristic curves of single-channel amplifier A

W2 = Setpoint value 2
IB = Current of amplifier B
IB BASIC = 0.0 mA
IB JUMP = 0.0 mA
IB MAX = 1000 mA

Value table 4

W1 (V)	0.0	2.0	4.0	6.0	8.0	10.0
IB (mA)						

Fig. 1/5: Characteristic curve of single-channel amplifier B



WORKSHEET

How does the characteristic curve change, if the basic current, jump current or maximum current are changed?

Conclusion

What does the comparison of the characteristic curves of amplifiers A and B demonstrate?

What is the purpose of changing the characteristic curve by setting the basic current, jump current and maximum current?

Exercise 1

Nur für den privaten Gebrauch For private use only Solo para uso privado Usage privé uniquement

Section C - Solutions

Embossing press

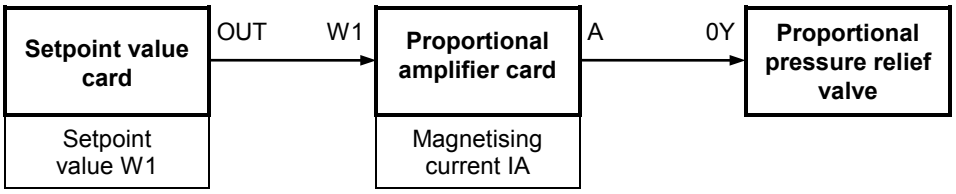


Fig. 1/1: Block diagram

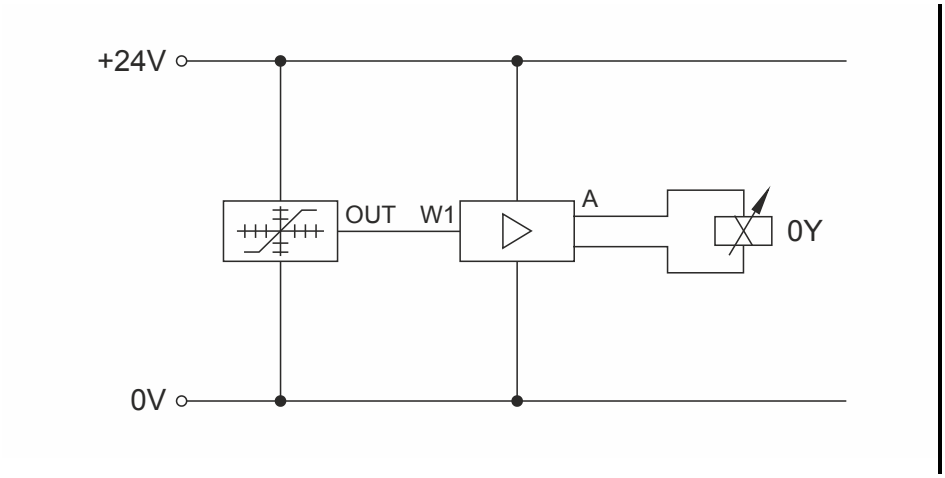


Fig. 1/2: Circuit diagram, electrical

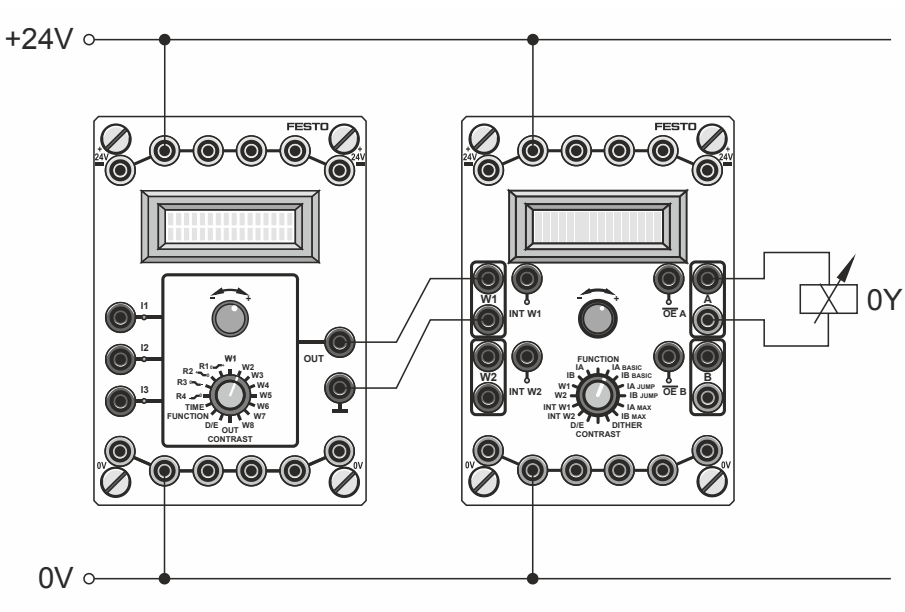


Fig. 1/3 Connection diagram

Components list

Item no.	*Quantity*	*Description*
1	1	Setpoint value card
2	1	Amplifier card
3	1	Proportional pressure relief valve
4	1	Power supply unit, 24 V
5	1	Cable set with safety plugs

Solution description

Construct the circuit according to the connection diagram. Connect the proportional pressure relief valve electrically only. Then place the setpoint value and amplifier card in the initial position. The required settings for this are listed in the tables. Different characteristic curves can be plotted by means of changing the basic current, jump curent and maximum current.

In order to measure the characteristic curve of the second single-channel amplifier, the output of the setpoint value card is to be connected to input W2. The proportional solenoid is to be connected to output B.

W1 = Setpoint value 1
IA = Current of amplifier A

Evaluation

W1 (V)	0.0	2.0	4.0	6.0	8.0	10.0
IA (mA)	0.0	200	400	600	800	1000

Value table 1

IA BASIC = 200 mA
IA JUMP = 0.0 mA
IA MAX = 800 mA

W1 (V)	0.0	5.0	10.0
IA (mA)	200	500	800

Value table 2

IA BASIC = 200 mA
IA JUMP = 100 mA
IA MAX = 800 mA

W1 (V)	0.0	0.1	5.0	10.0
IA (mA)	200	300	550	800

Value table 3

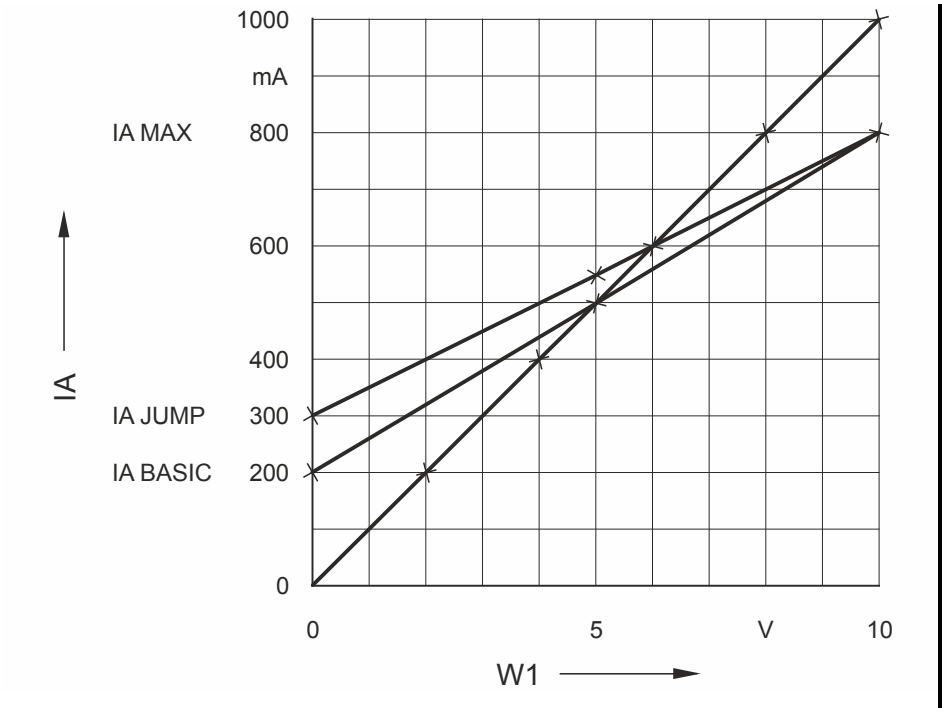


Fig. 1/4: Characteristic curves of single-channel amplifier A

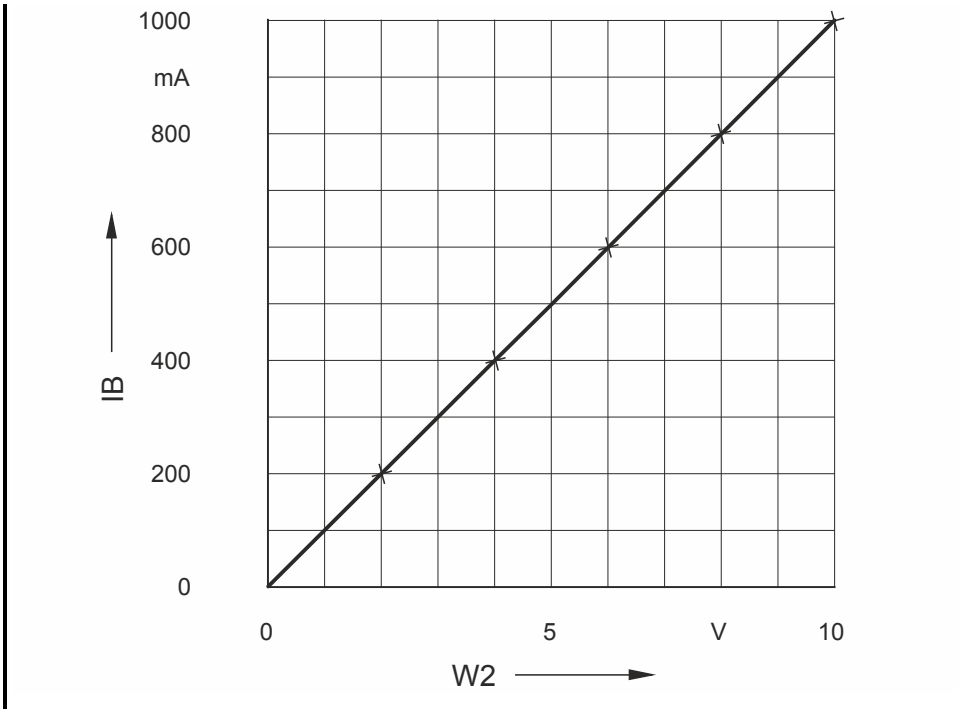
Solution 1

W2 = Setpoint value 2
IB = Current of amplifier B
IB BASIC = 0.0 mA
IB JUMP = 0.0 mA
IB MAX = 1000 mA

Value table 4

W1 (V)	0.0	2.0	4.0	6.0	8.0	10.0
IB (mA)	0.0	200	400	600	800	1000

Fig. 1/5: Characteristic curve of single-channel amplifier B



Conclusion

- The slope of the characteristic curve changes as a result of the basic current, jump current and maximum current. The slope corresponds to the

  amplification factor $K = \frac{\text{Change of output signals}}{\text{Change of input signals}} = \frac{\Delta O}{\Delta I}$

- The comparison shows that the two single-channel amplifiers are identical.
- The amplifier is adapted to the characteristics of the proportional valve by means of setting the basic current, jump current and maximum curent.

  Reason:
  The amplifier converts an input voltage (setpoint value) into an output current for the valve solenoid, whereby the following applies:

  - max. setpoint value produces max. magnetising current and max. valve opening,
  - min. setpoint value produces min. magnetising current and min. valve opening.

Solution 1