Examples of Applications using Proportional and Servo Valves

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1 Introduction

More and more demands are being placed upon proportional technology. Designers of hydraulic systems using this technology are also being faced with an increase in the number of requirements.

In addition to a thorough knowledge of how devices function, several important criteria must be taken into account when designing circuits:

- Natural frequency of a system
- Correct spool size

  Pressure drop at the control lands!
- Control range - Q_{min}/Q_{max}
- Effect of changes in mass, velocity, pressure and viscosity

  Limits of time dependent deceleration
- Are pressure compensators necessary?

  Meter-in pressure compensator or meter-out pressure compensator
- Are deceleration or counterbalance valves necessary?
- Pressure intensification in single rod cylinders and meter-out pressure compensators

  Total pressure at motors!
- Is an increase in closed loop control Δp at pressure compensators appropriate or necessary?
- Is open loop control at all possible or must closed loop control be implemented?
- Selection of valves with sufficiently fast response for theoperations to be carried out, particularly in closed loop control.

The applications which are described in the following pages are examples from various sectors of industry and represent a cross section of typical tasks performed by hydraulic systems. It is clearly shown how the above mentioned criteria are taken into account.

It is essential, when planning open loop control systems and drives in proportional hydraulics to have a precise definition of the intended application. If an exact definition exists, it is possible - almost without exception - to determine the best solution straight away.

2 Radio Control for Suspended Mono-rail System in the Mining Industry

Cable-driven suspended mono-rail systems are used in the mining industry to transport material and people.

Hydrostatic drives have proved to be suitable for cable-driven transport systems, due to the simplicity of speed adjustment (whilst maintaining the required tractive forces) over the entire range of speeds.

The change in flow delivered by the pump and hence the speed of the rail system is dependent on the control pressure. The swivel angle of the axial piston pump (3) is proportional to the pilot pressure of the pilot unit

To ensure that the system may be operated at any time, two systems are provided for the control of the pilot pressure for the adjustment of the pump:

- System with a 3-way proportional pressure control valve, Type 3 DREP6C (2)
- System with a manually operated pilot unit Type 2TH7 (1)

The proportional pressure control valve is actuated by means of radio control. The driver uses a portable transmitter for this purpose. High frequency transmission between transmitter and receiver takes place in the 30 MHz frequency range. The frequency-modulated signals received are pulse code modulated, which in comparison to other systems, offer the highest possible degree of reliability in transmission.

During manual control of transmission, the operator is linked to the driver of the train by radio via the pilot unit 2 TH 7 (1) near the driver. A coaxial cable runs alongside the entire length of rail for the transmission of radio signals.

Both the proportional pressure control valve 3 DREP6C and the pilot unit 2TH7 have been modified to and approved to BVS (German mining authority) specifications.

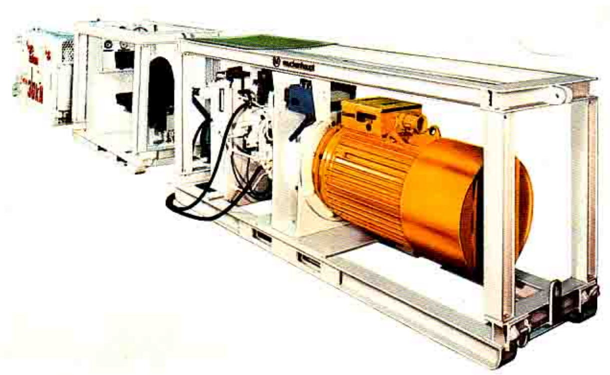


Fig. 273: *Driver unit for suspended mono-rail*

Fig. 274: *Suspended mono-rail*

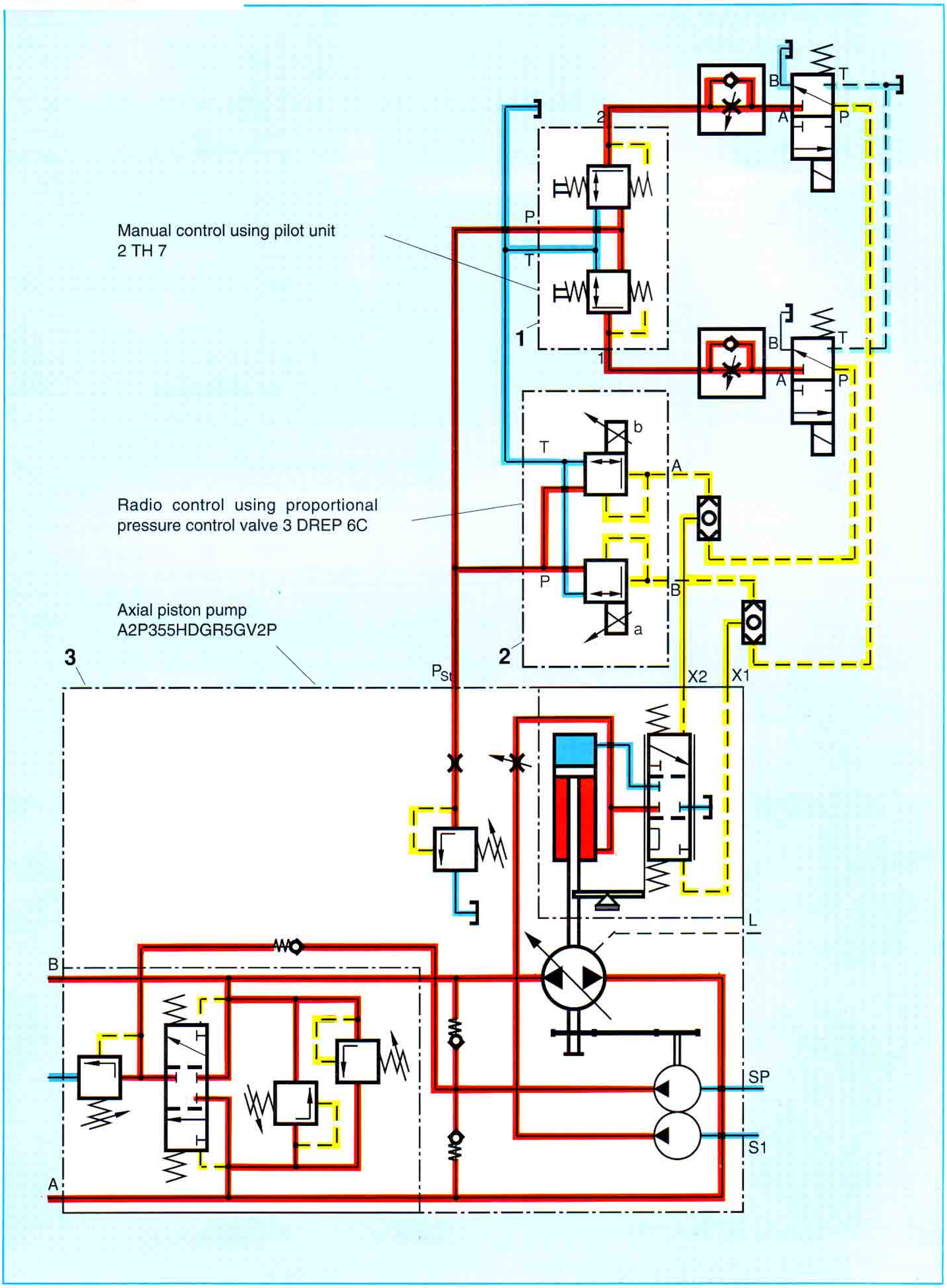


Fig. 275: *Hydraulic circuit diagram for suspended mono-rail*

3 Transmission in Ladle Car in Blast Furnace

Converter linings are subject to wear and require regular replacement. Hence, the converter must be moved to various positions with the the vessel changing vehicle.

Vessels are changed in 4 Phases:

- The dismantled vessel is moved to its parking point
- The vehicle moves to the feed stand
- The overhauled vessel is moved to the blasting stand
- The old vessel is moved from the parking point to the feed stand

Technical Data

- Vehicle diameter 16 m
- Height of vehicle with vessel 9 m
- Total weight of vehicle + vessel 1200 t

The maximum speed of the vehicle is 15 m/min. This corresponds to a speed of 3.2 rpm at the four drive wheels. The speed must be smooth with sensitive continuous closed loop control from almost zero to 15 m/min.

It must be possible to approach individual positions with a relatively high degree of accuracy. At one crossing point, the vehicle is rotated through 90° about the centre. Here the complete vehicle is raised and, after rotation, lowered onto the new pair of rails. During this operation, the positioning accuracy is ±30 mm, which is not negligible, considering the dimensions and weights involved.

All transmission procedures are controlled via the proportional directional valve (1). Adverse effects due to various rail frictions, loads, viscosities etc. are compensated for, by means of meter-out pressure compensators (2) in lines A and B. These meter-out pressure compensators are integrated into the manifold, in the form of 2-way pressure reducing cartridge valves. Pressure relief valves (3) built into the cover, enable Δp to be adjusted at the orifice (proportional directional valve spool). This is necessary as the proportional directional valve, type 4WRZ32, cannot cope with the maximum flow of 624 L/min at a fixed Δp of 8 bar at the sandwich plate pressure compensator. A higher Δp at the orifice results in a higher flow. The proportional directional valve is manually pilot operated via a manual control unit. It is important for the operator to know that a particular angle of deflection of the control unit always produces the same speed. The meter-out pressure compensators ensure that this is the case, even when the above mentioned adverse effects change.

Fig. 276: *Hydraulic transmission of vessel changing vehicle*

Fig. 277: *Vessel changing vehicle is moved into position via the rail crossing point*

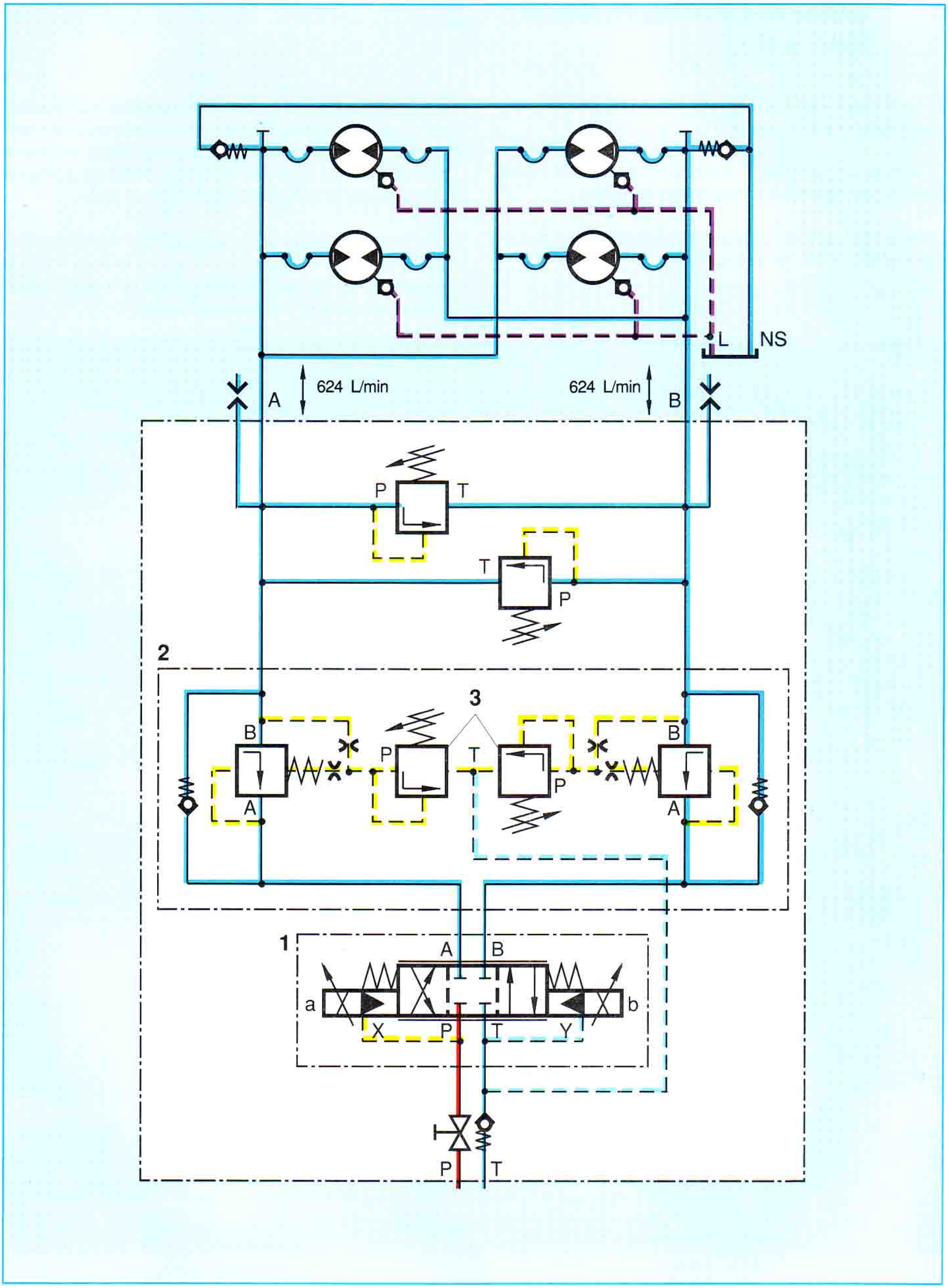


Fig. 278: *Hydraulic circuit diagram for transmission of a vessel changing vehicle*

4 Lifting and Placing Device in a Rolling Mill

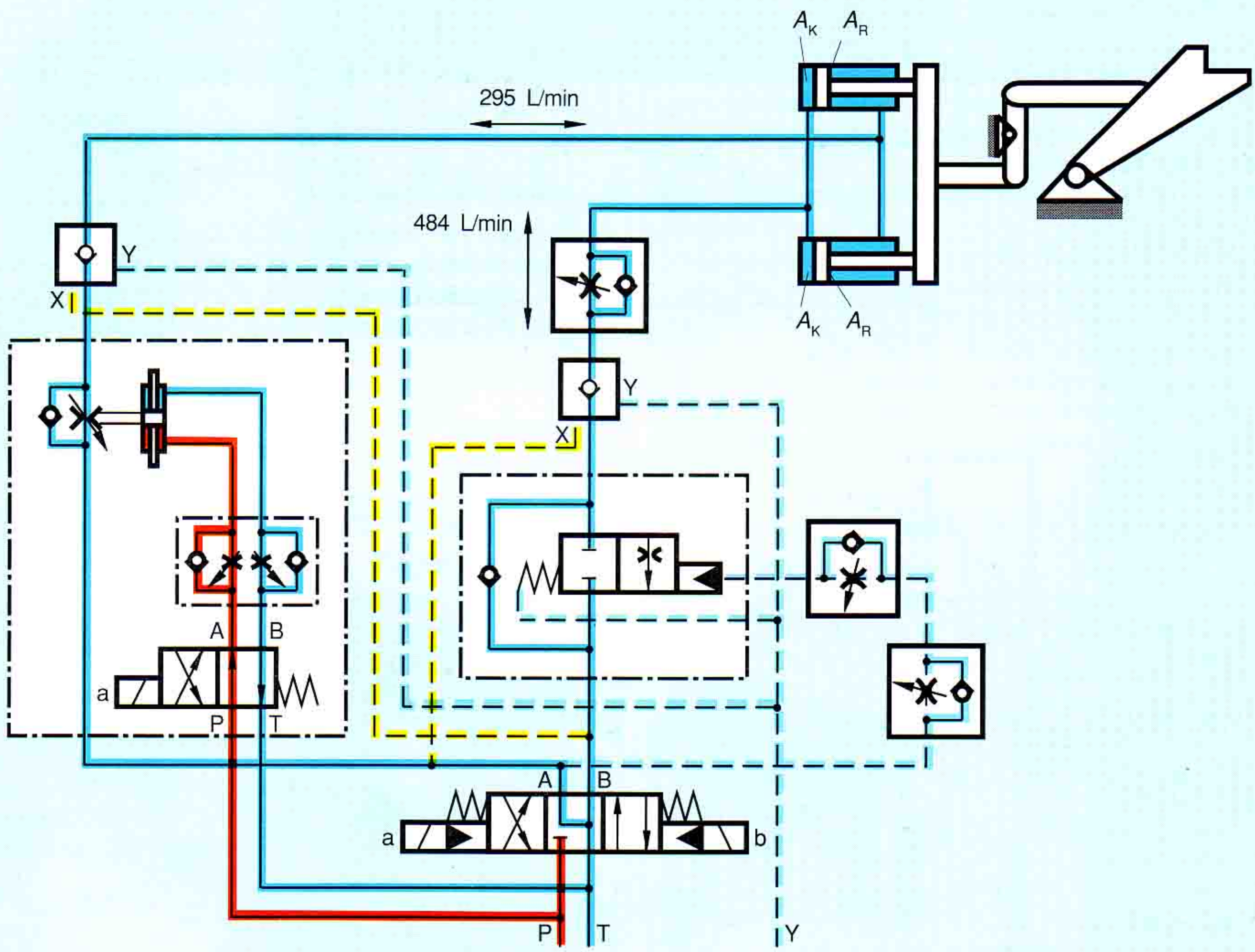
In a previous version *(Fig. 279)*, 8 components were necessary for the control of the lifting cylinder.

To individually pipe these devices, or to mount or insert them into a manifold was costly and complex.

Optimum adjustment and adaptation of all devices required a considerable amount of time.

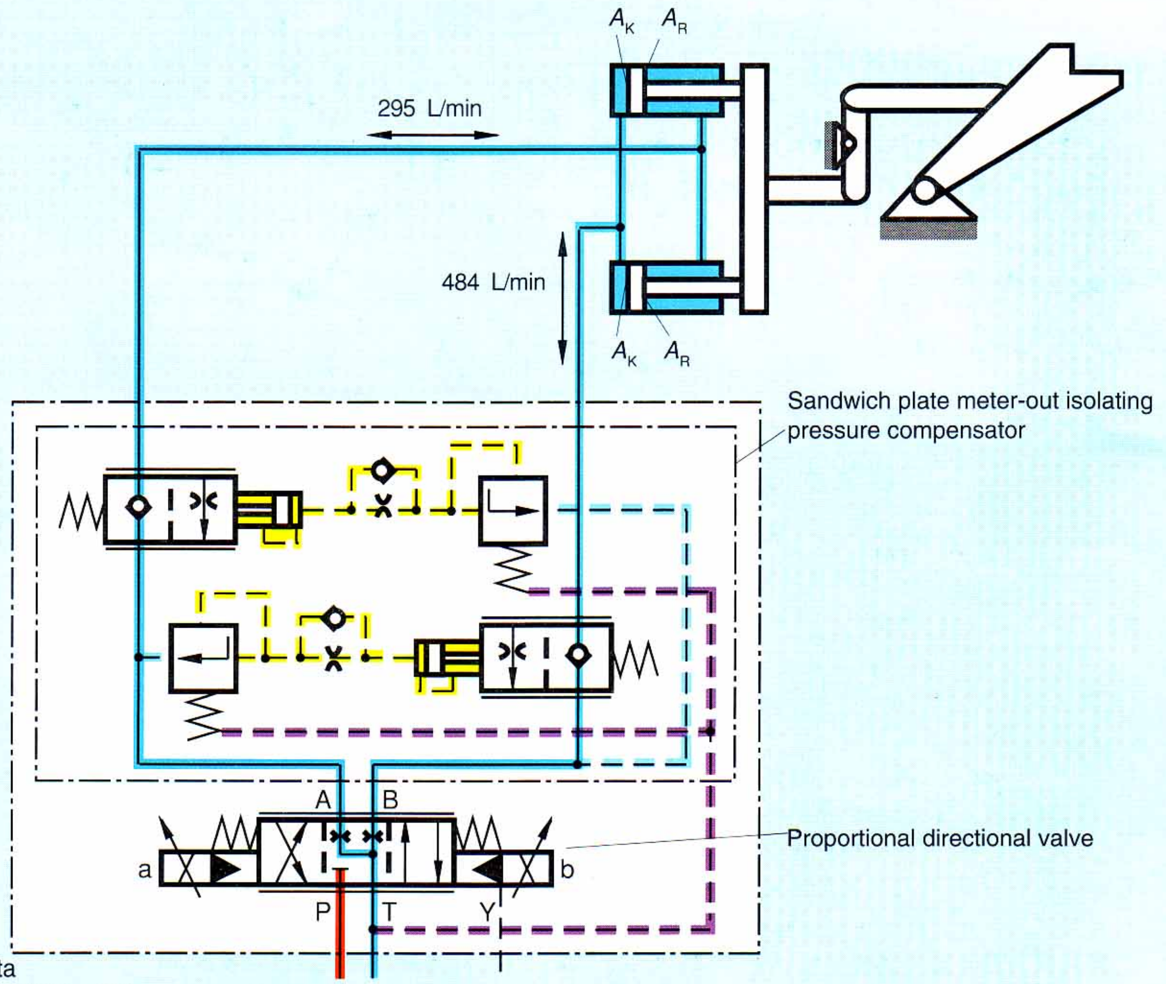
In the new version *(Fig. 280)* with a proportional directional valve, only one additional device needs to be connected via the subplate, or mounted onto a manifold. This is due to the fact that the meter-out isolating pressure compensator is designed as a sandwich plate.

This meter-out isolating pressure compensator contains two pressure compensators connected in lines A and B which provide complete isolation, when the proportional directional valve is in the neutral position.



Technical Data
2 Cylinders 160/100 x 800
A_K = 201 cm^2
A_R = 122,5 cm^2
v = 0,2 m/s
m_{min} = 10000 kg
Q_{max} = 484 L/min

Fig. 279: *Previous solution for the control*



Technical Data
2 Cylinders 160/100 x 800

A_K = 201 cm²
A_R = 122,5 cm²
v = 0,2 m/s
m_{min} = 10000 kg
Q_{max} = 484 L/min

Fig. 280: *New solution with proportional directional valve*

5 Lift in Welding Line

The welding line is used in the production of car bodies. The system is 30 m long. All 12 lifting stations are lifted and lowered simultaneously. Material is transferred or deposited at the centre of lift. The transfer speed must not exceed 0.15 m/s, or the sheet metal parts will be thrown out of position. On the other hand, the lifting and lowering processes should be completed as quickly as possible.

For this application, a proportional valve together with electronic devices for position-dependent decelerations is used.

Electronic proximity switches (so-called analogue initiators) are moved along metal cams. As the initiator approaches the cam, the output voltage is reduced to 0 V by analogue means. This voltage is fed to an amplifier, which is specially designed for this purpose and hence controls the proportional solenoids of the proportional directional valves. This arrangement does not represent a closed loop control system but instead a position-dependent open loop control system, which provides an analogue measurement of displacement during the deceleration phase.

As shown in the example, at any position, speed may be reduced to any value and increased again to the origional value by means of a cam. Of importance here is the distance X between cam and mean travel path between the two end cams.

As analogue measurement of position is only required during deceleration, systems with any length of stroke (e.g. transmission systems) may be designed with this equipment.

This technology is primarily used when a drive must approach a particular position with a relatively high degree of accuracy under conditions of varying kinetic energy.

If the speed of a drive is higher than approx. 1 m/s, this sytem is then generally preferable to one using time-dependent decelerations.

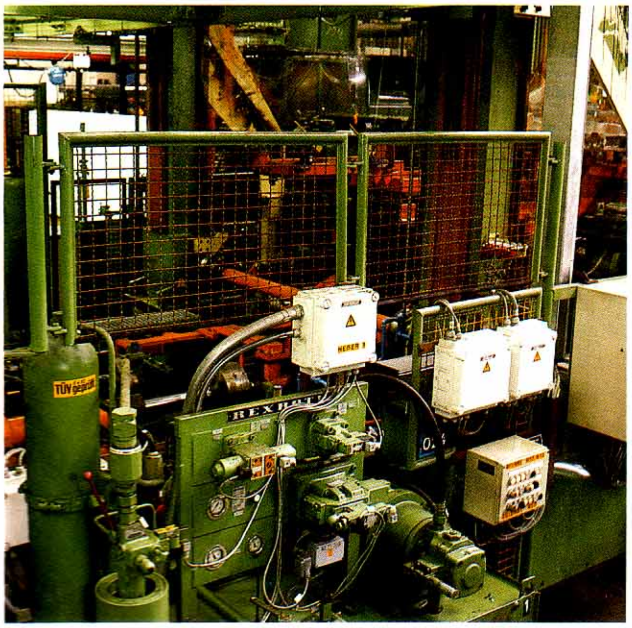


Fig. 281: *The accumulator (left) provides the 460 L/min necessary for the acceleration procedure. The V4 vane pump (right) fills the accumulator during "stationary phases". The proportional directional valve, type 4WRZ25 required for the control process is positioned to the right.*

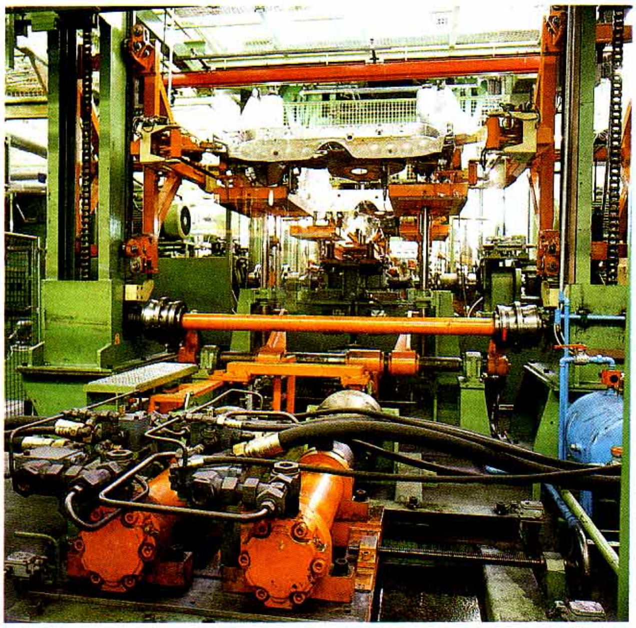
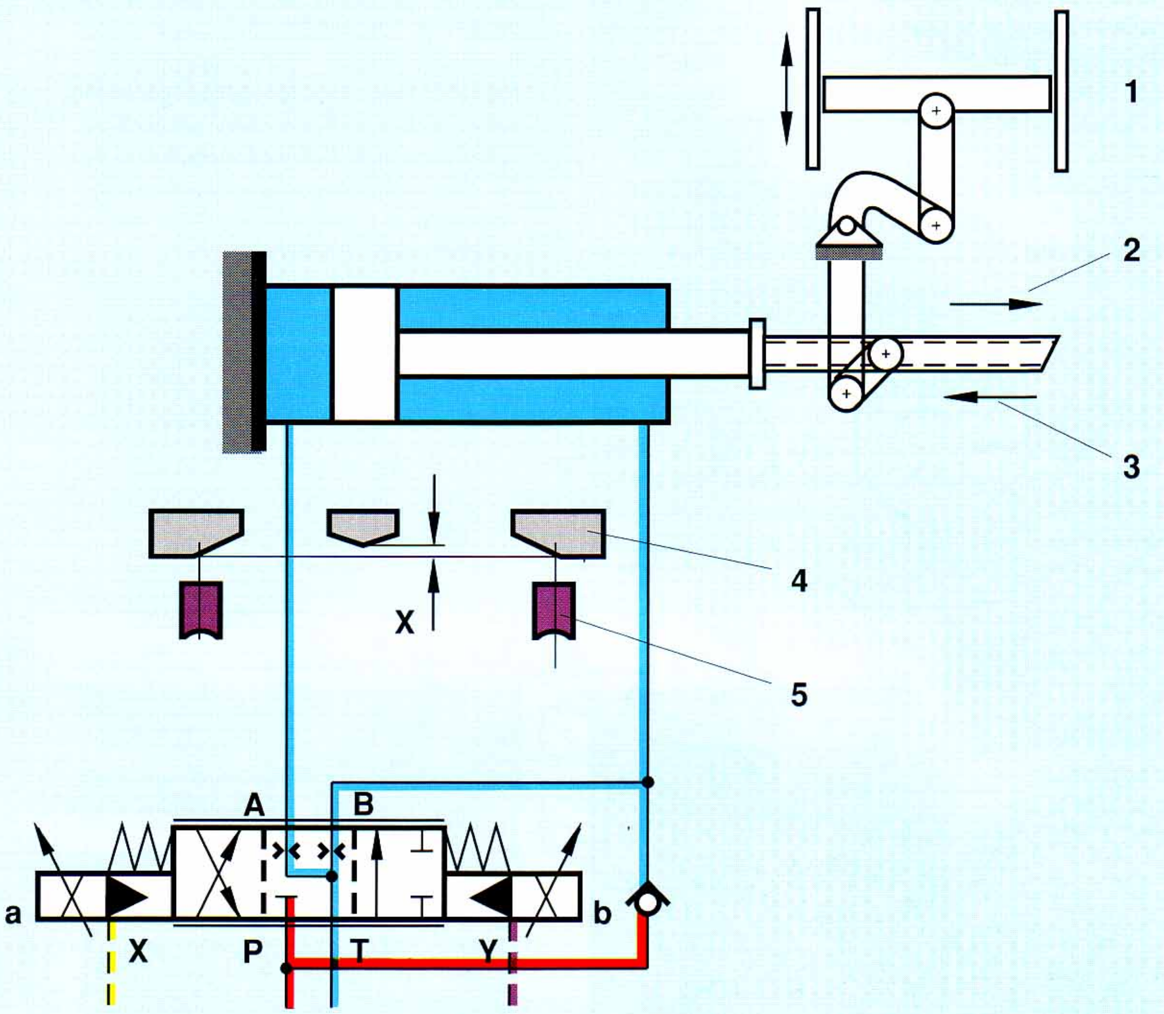


Fig. 282: *One cylinder - the other is on standby - moves, via a lifting mechanism, all 12 stations simultaneously.*



1 12 lifting stations
2 Lifting
3 Lowering
4 Deceleration cam
5 Analogue initiator

Technical Data

D	=	140	mm
d	=	100	mm
H	=	450	mm
$v_{max. Cyl.}$	=	0,5	m/s
$v_{max\ stroke}$	=	0,6	m/s
m	=	8000	kg
$m_{tot.}$	=	11520	kg
i	=	1,2	

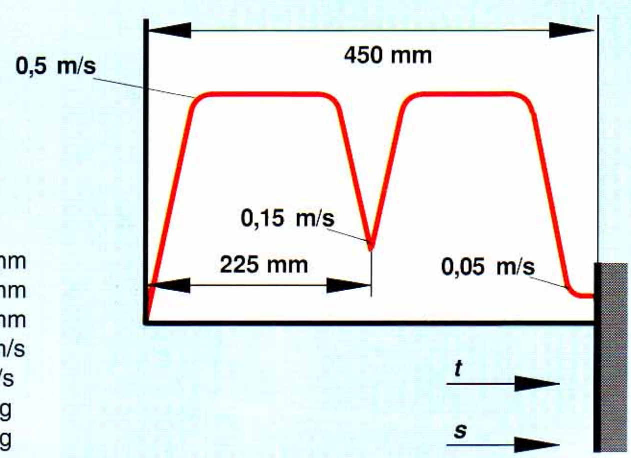


Fig. 283: *Basic block diagram of a hydromechanical drive for a welding line (above) and its sequence of movements (below right)*

6 Chain Conveyer-Drive Cylinder

In a hot rolling mill, the coils at the end of a hot conveyer line must be moved to a storage place. The temperature of the coils at the take-up reel is approx. 800 - 1000 °C. During transport, coils are to be cooled to a temperature of approx. 500 - 600 °C. Therefore the conveyer chain often includes an outdoor section outside the bay.

The total length of the coil conveyer chain is 280 m.

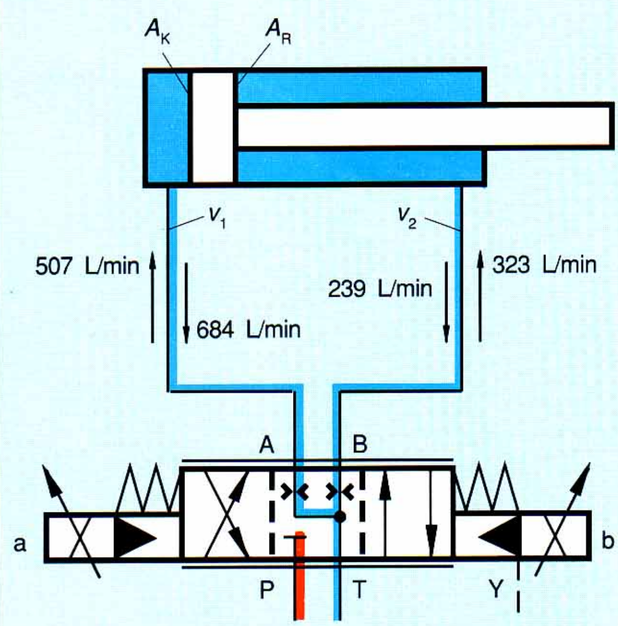
At a transfer station, the coils coming from a shorter chain driven by a hydraulic motor are transferred to the chain running at floor level. This chain is driven by a drive cylinder at a regular pulse/stroke of 3600 mm.

At the beginning of the stroke, the drive is connected to the chain. On completion of the stroke and disengagement of the drive, the chain pauses whilst the stroke returns. After return to the initial position, a new cycle begins as soon as the transfer station has transferred a new coil.

In a previous version, the control was designed using several components. Correct adjustment was complex and time consuming.

With the new concept, open loop control is achieved with only one proportional directional valve. This arrangement is considerably less expensive and much easier to handle. The acceleration and deceleration ramps as well as the speeds are easily adjusted via the front plate on the proportional amplifier.

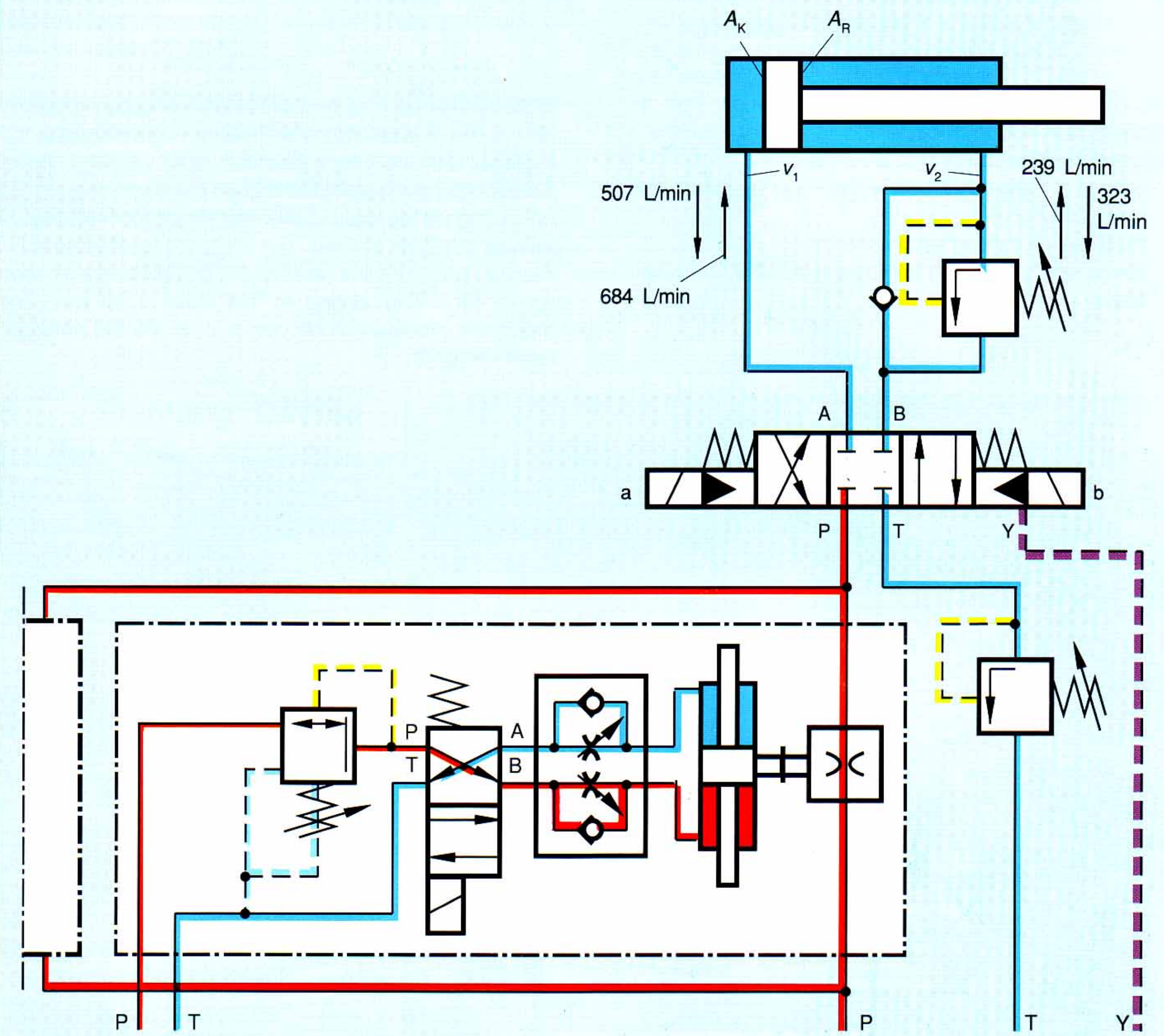
Fig. 284: *Chain conveyer*



Technical Data

D =	220	mm	m_{min} =	560	t
d =	160	mm	m_{max} =	2800	t
H =	3850	mm	A_K =	380	cm²
v_1 =	0,222	m/s	A_R =	179	cm²
v_2 =	0,3	m/s	Q_{max} =	684	L/min

Fig. 285: *New concept of open loop control with proportional directional valve*



Technical Data

D =	220	mm	m_{min} =	560	t
d =	160	mm	m_{max} =	2800	t
H =	3850	mm	A_K =	380	cm^2
v_1 =	0,222	m/s	A_R =	179	cm^2
v_2 =	0,3	m/s	Q_{max} =	684	L/min

Fig. 286: *Open loop control in previous version*

7 Open Loop Control for Airfreight Lifting Platform

The open loop control system must comply with the following conditions:

- smooth acceleration and deceleration
- control of speed independent of load in all transmission phases
- leak-free closure when stationary
- low power losses with fixed displacement pump operation

Constant speed, independent of load, is achieved during lift via the 3-way meter-in pressure compensator (3) together with the 2-way pressure relief cartridge valve. This pressure compensator has a 4 bar control spring. By unloading via the directional valve (6), pump flow may be unloaded to tank at 4 bar. The pressure relief valve (5) in the load pressure line permits the control pressure drop Δp to vary. The setting in this case is 10 bar. The maximum pressure of the pump is set via the pressure relief valve (4).

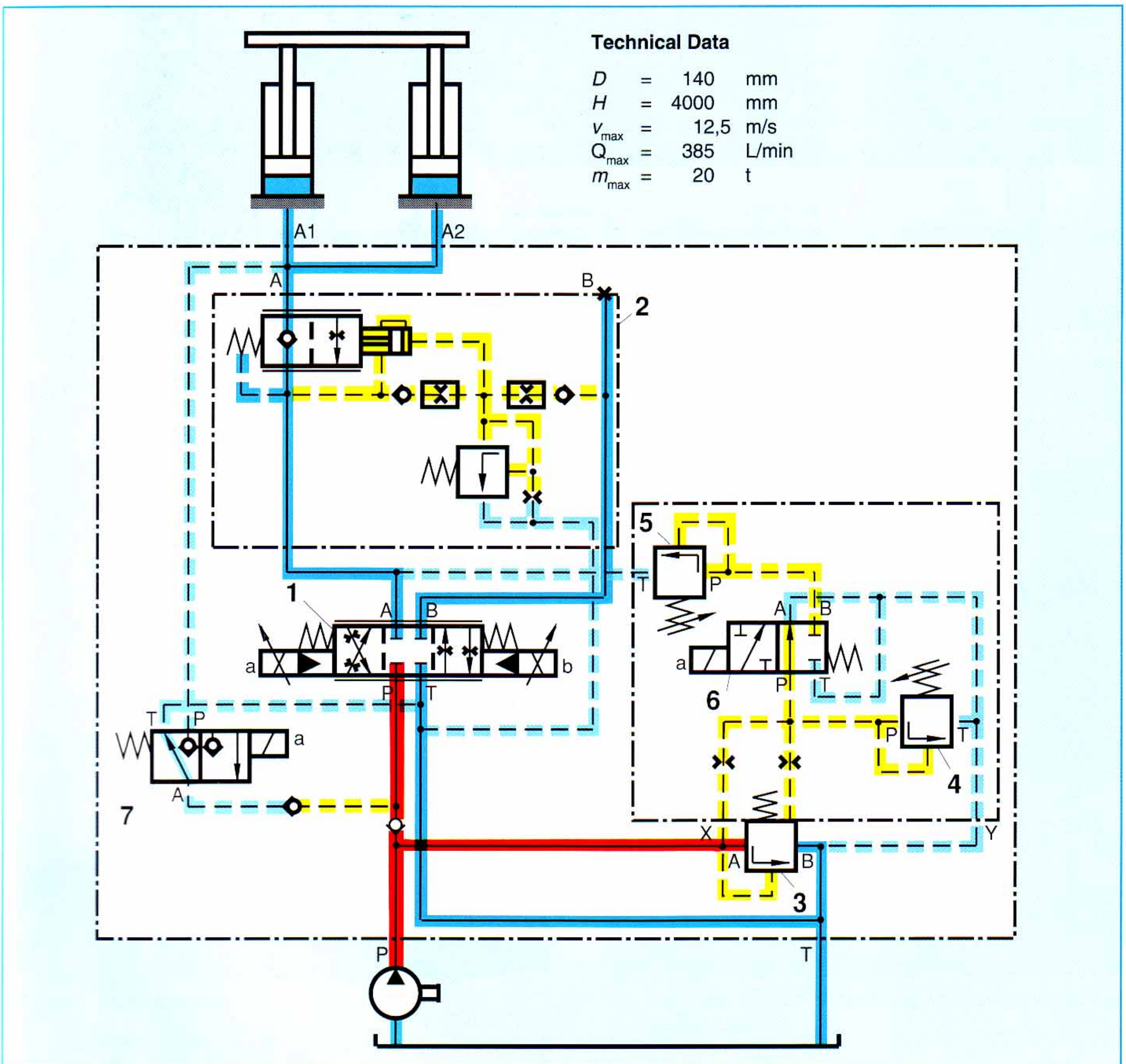


Fig. 287: *Synchronous mechanical open loop control for airfreight lifting platform*

During lift, pump pressure is automatically set to the required load pressure + control Δp of 10 bar at the orifice (i.e. control land P to A).

When the lift is stationery or lowered, the electric motor of the fixed displacement pump is switched off. Therefore, the directional poppet valve (7) is required for the pilot oil supply of the proportional directional valve (1) and meter-out pressure compensator (2).

The pressure drop at control land A to T is maintained constant during lowering by the meter-out isolating pressure compensator (2). Hence, the speed is also maintained constant, independent of changes in load.

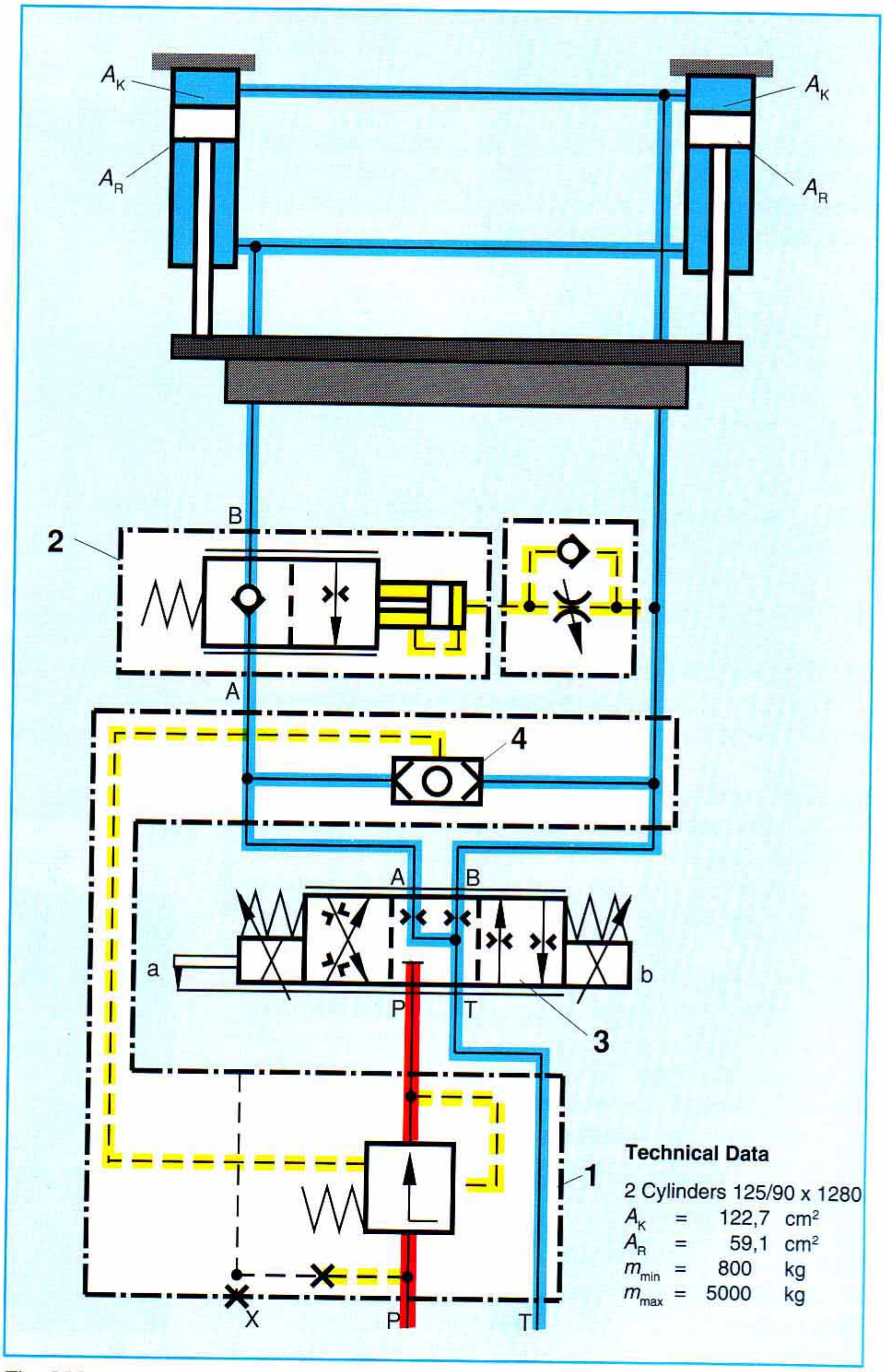
In addition, the meter-out isolating pressure compensator provides leak-free isolation when the lift is stationery and acts as a non-return valve during lift.

8 Stacking Device for the Paper Industry

A two-way meter-in pressure compensator (1) (sandwich plate) is used in order to avoid pressure intensification in the single rod cylinders.

Due to the negative (pulling) load a counterbalance valve (2) is necessary. When lowered, the load must be taken up by the counterbalance valve to ensure that the pressure drop from P to B at the proportional directional valve (3) remains constant at 8 bar.

Load pressure is measured in the actuator lines via a shuttle valve (4). This shuttle valve (4) is integrated into the pressure compensator.



Technical Data

2 Cylinders 125/90 x 1280

A_K	=	122,7	cm²
A_R	=	59,1	cm²
m_{min}	=	800	kg
m_{max}	=	5000	kg

Fig. 288

9 Manipulator for 2 Presses

Gas bottles are produced on a pair of hot forming and hot stretching presses. Transport between presses and feed is fully automatic. Manipulators - consisting of upper cars for longitudinal movements and lower cars for vertical movements - carry out all movements.

Only the operations of the upper car will be considered here. The maximum distance to be travelled is 6 m. Over this distance 5 positions must be approached with a relatively high degree of accuracy.

The drive takes the form of a hydraulic motor driving a rack and pinion. A pilot operated proportional directional valve (1), type 4 WRZ 16 E 100 is used for the control of the movements.

Electrical control of the drive is via a digital positional amplifier VT 4630. With this amplifier, hydraulic drives in proportional or servo valve open loop control systems are positioned via digital BCD signals.

Distance is measured incrementally via a rotary pulse generator or glass scale device. Before the required position is reached, deceleration dependent on distance is introduced, whereby the command signal sent from the valve is gradually reduced to zero. The valve is then closed. The starting process is set via a time ramp.

The amplifier enables positions to be set either internally via 5-digit decade switches, or externally via a freely programmable control. Similarly, the 5-digit position display may be installed internally or externally.

When setting the positions externally via a PC system, any number of positions may be set. When set internally, the number of positions is limited to 9.

Speeds, acceleration ramps, deceleration ramps (for inching) and deceleration distances for distance-dependent deceleration are set via the potentiometers on the front plate of the amplifier. The setting of the 5 positions to be approached takes place externally via PC control.

In this case, the distance is measured via a rotary pulse generator at 1250 pulses/revolution. At a pinion diameter d_0 = 159 mm, 2 revolutions (= 1 m distance travelled) produce 2500 pulses. This pulse count is quadrupled by a suitable circuit in the amplifier. Hence, a 1 m distance is transformed into 10,000 pulses (1 pulse = 0.1 mm). Hence the required positioning accuracy of ±1 mm is ensured.

10,000 pulses (= 0 to + 10 V) are available on the amplifier for deceleration. Calculated deceleration is 0.75 m = 7500 pulses.

In order to protect the hydraulic motor during an "emergency stop" (the proportional directional valve is no longer closed via time ramp or distance dependent deceleration control, but is allowed to close in its own minimum natural closing time of approx. 70 ms) relief and anticavitation valves (2) have been installed.

To ensure that the feed side is filled, a non-return valve (3) with a 3 bar cracking pressure is installed into the tank line.

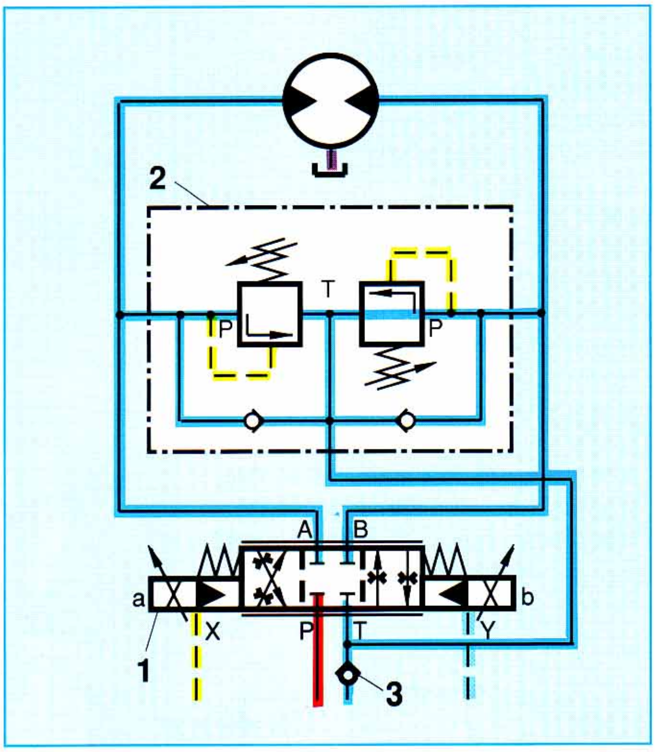


Fig. 289

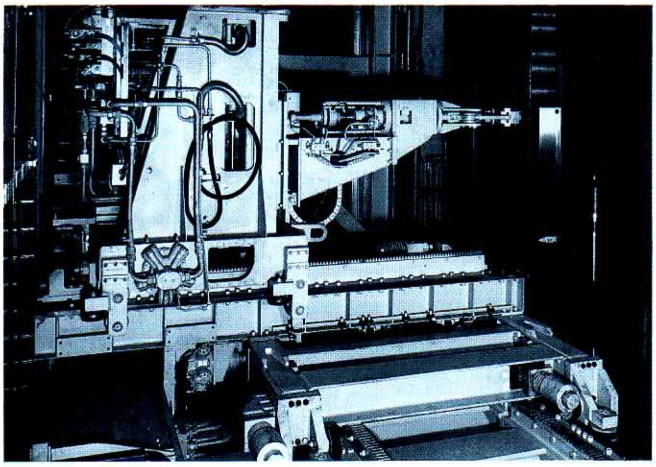


Fig. 290

10 Slide Control Unit

Slide control units in transfer lines mainly feature cylinders with an area ratio of 1:2. A regenerative circuit is used in these cases. Compact manifolds in sizes 6, 10 and 16 of modular design are directly mounted onto the unit cylinders. Proportional directional valve (1) acting as a rapid traverse valve enables shock-free starting and deceleration of relatively large masses. Rapid traverse speeds of up to 25 m/min are often achieved in time-dependent units in transfer lines. With a flow regulator (2) the feed rate is set by conventional means.

Optimum backpressures are set automatically at the load-dependent counterbalance valve (3) in each phase of the operating cycle.

Rapid traverse speeds as well as accelerations and decelerations may be easily set at the electrical proportional amplifier.

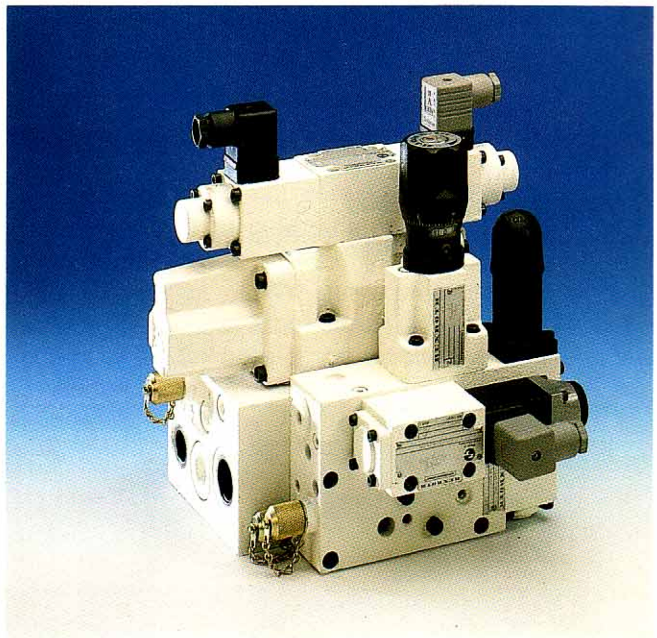


Fig. 291: *Manifold shown in circuit in Fig. 292*

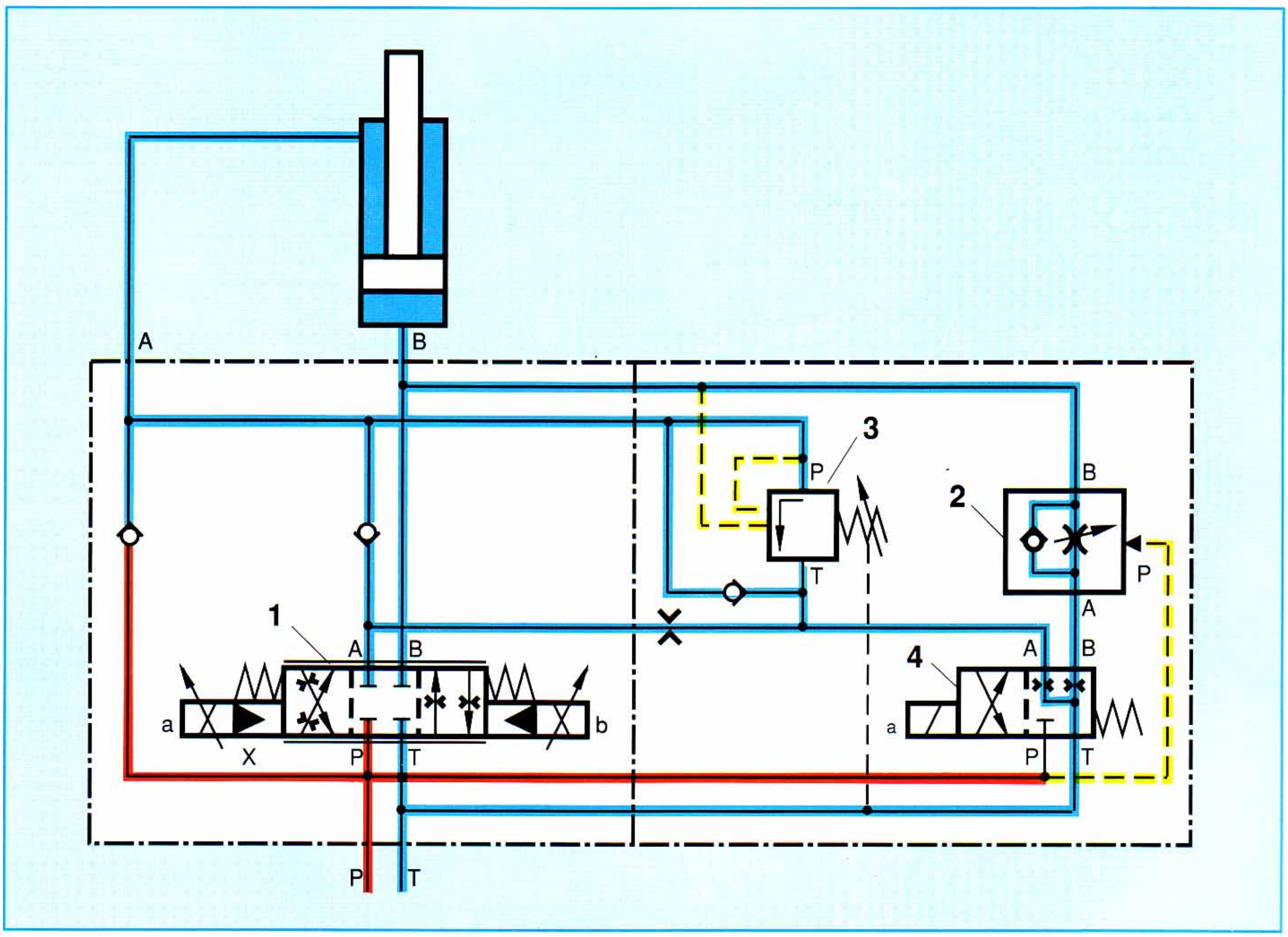


Fig. 292: *Hydraulic circuit of manifold shown in Fig. 291*

11 Stage Control in a Theatre

Requirements of hydraulics:
- Absolute jolt-free acceleration and deceleration of all movements
- Smooth variable speed
- Synchronization of both pivot arms

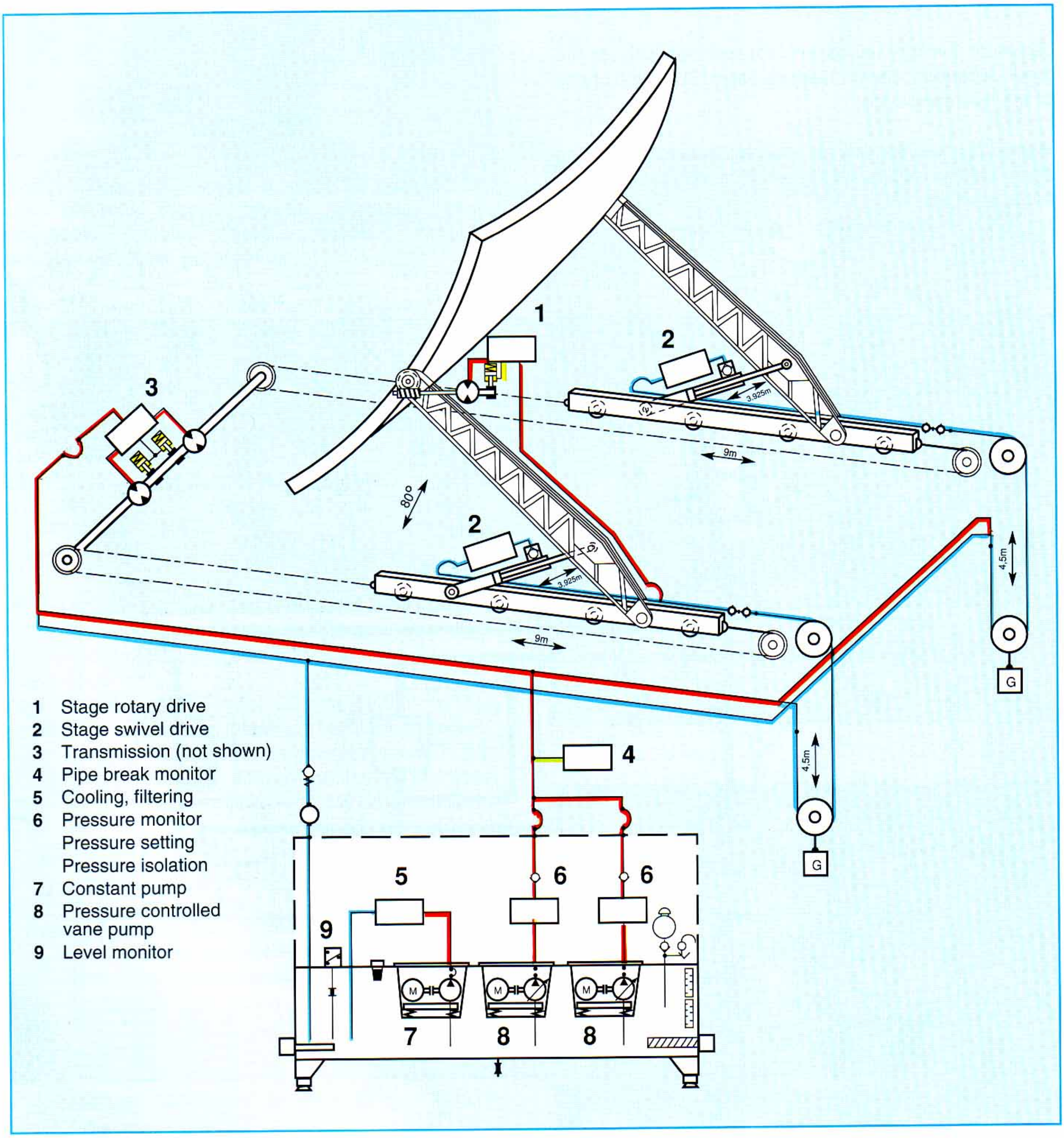


Fig. 293: *Illustration of stage control*

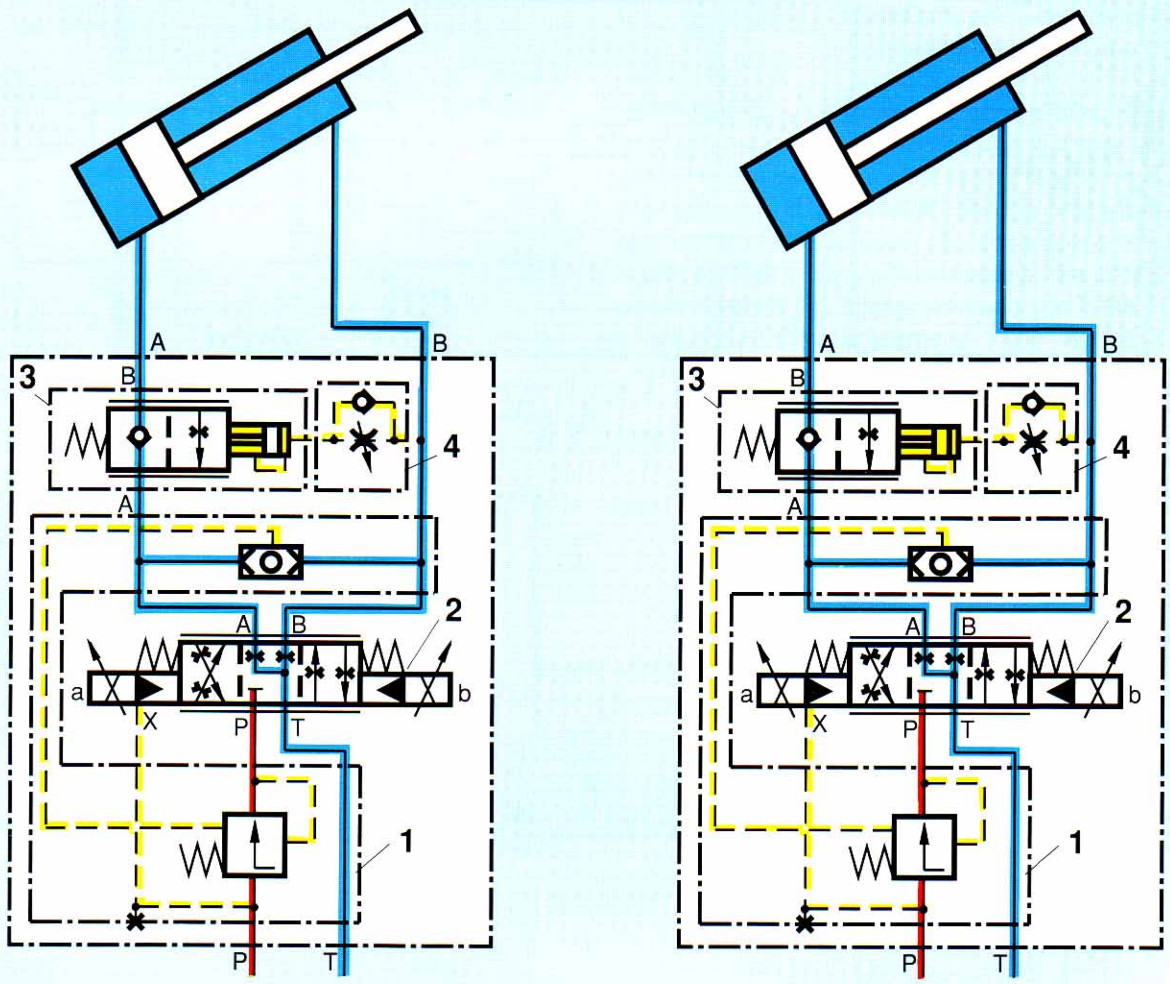
11.1 Stage Swivel Drive

The stage is raised and lowered by means of a cylinder attached to each of the swivel arms. The cylinders are mounted via pivot bearings to the chassis and swivel arms so that they may easily be moved in all directions. Lifting and lowering movements are carried out via pilot operated proportional directional valves (2) in a closed loop control circuit. The relatively low dynamic response of the drive permits the use of these devices.

As a result of the kinetic characteristics of the system, various forces occur over the stroke of the cylinders The pressure compensators (1) connected upstream of the proportional directional valves compensate for the effects of these various forces. The closed loop control is therefore only required to remove synchronization errors.

Pivot angles are determined via potentiometers at the fulcrum points of the cylinders on the chassis.

The use of meter-out pressure compensators is not possible due to the cylinder area ratio of 1:2.54. For this reason, deceleration valves (3) are required in the A-lines, in addition to the meter-in pressure compensators in the P-lines. This arrangement also ensures leak-free cut-off of the full bore of the cylinder, when the drive is stationary.



Technical Data

2 Cylinders

A_K = 254 cm²

A_R = 100 cm²

v_{min} = 4 m/s

v_{max} = 70 m/s

Fig. 294: *Control for stage swivel drive*

11.2 Stage Rotary Drive

Stage rotation (inclination) about its centre axis is carried out by a hydraulic motor via a worm gear with a transfer ratio of 150:1. The angular speed of the stage must be smoothly variable from almost zero to 1 rpm. For this reason, an axial piston low-speed motor, type MCS is used. For these conditions, this motor ensures low torque fluctuations and low pressure fluctuations, and therefore a minimum smooth angular speed of 0.5 rpm.

A meter-in pressure compensator (1) is connected upstream of the proportional directional valve (2) to provide the load compensation. It is not possible to use a meter-out pressure compensator, as the motor would be subject to an excessively high load at the operating pressure of 150 bar. The total max. pressure at the motor is 300 bar. The acceleration pressure which occurs during the acceleration phase would have to be added to double the operating pressure. The maximum permissible total pressure would then be exceeded.

The meter-in pressure compensator only compensates for load (Δp kept constant at the orifice) when the load direction is positive. For this reason, deceleration valves (3) are installed into actuator lines A and B. A further task of this device is to provide leak-free cut-off when the drive is stationary for safety reasons. To ensure that the stage is reliably held in any position, inspite of internal leakage of the motor, the motor is equipped with hydraulically released disc brake.

The control of the drive, i.e. actuation of the proportional directional valve is via a manual control unit.

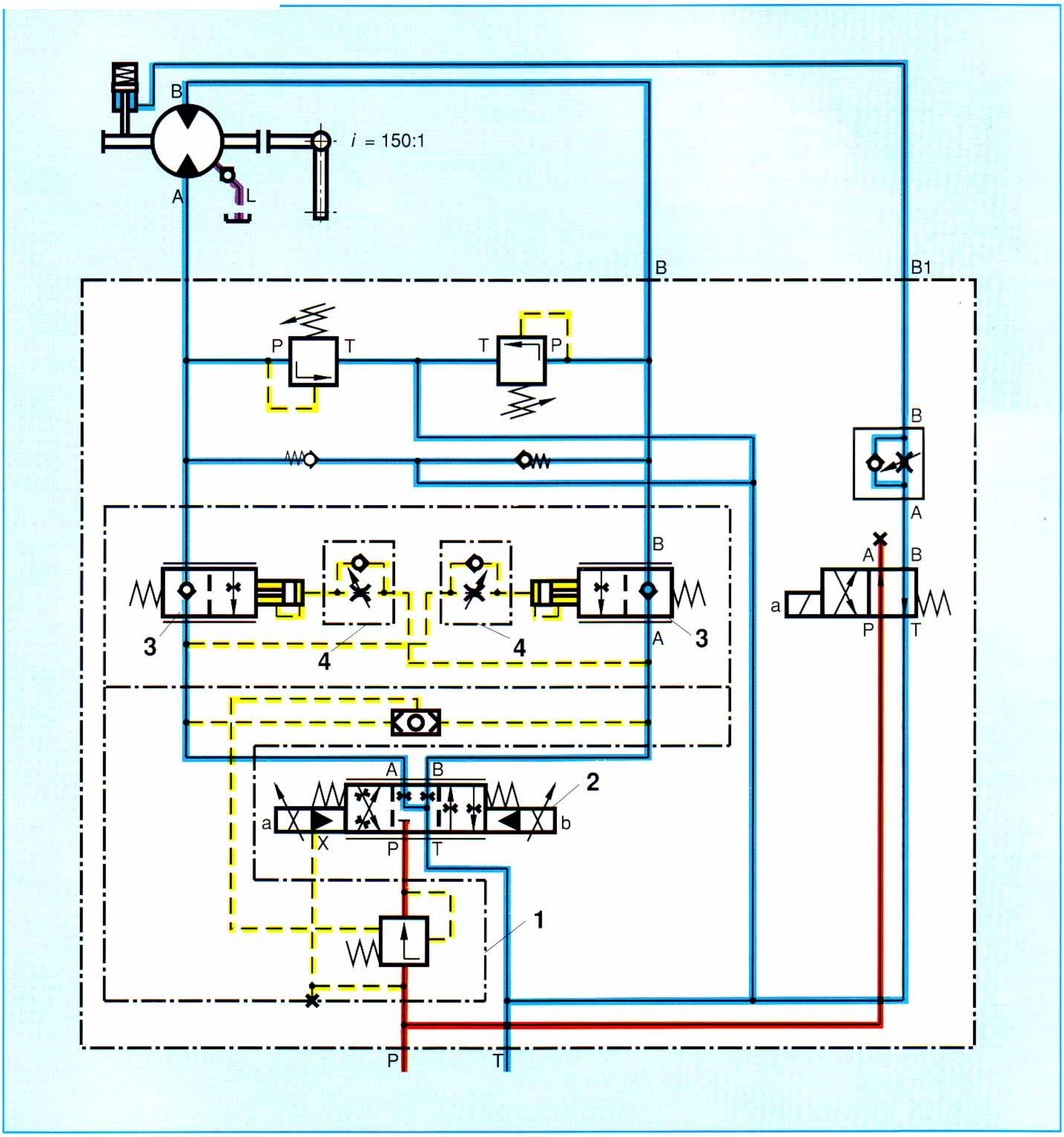


Fig. 295: *Control for stage rotary drive*

12 Injection Moulding Machine

The high requirements placed upon modern injection moulding machines with respect to the continuous quality of finished parts, require closed loop control to be increasingly used for the injection process. Using closed loop control, deviations found in the finished component are reduced by a factor of nine. The starting and settling down of a closed loop control machine is achieved after only a few cycles. Therefore the production quality of the parts is attained.

A further increase in quality, even in complex parts may be achieved when an internal workpiece pressure measurement is incorporated into the closed loop control circuit.

The injection rate curve is determined on the basis of the process data.

The stroke of the injection cylinder is measured by a position measuring system and processed accordingly.

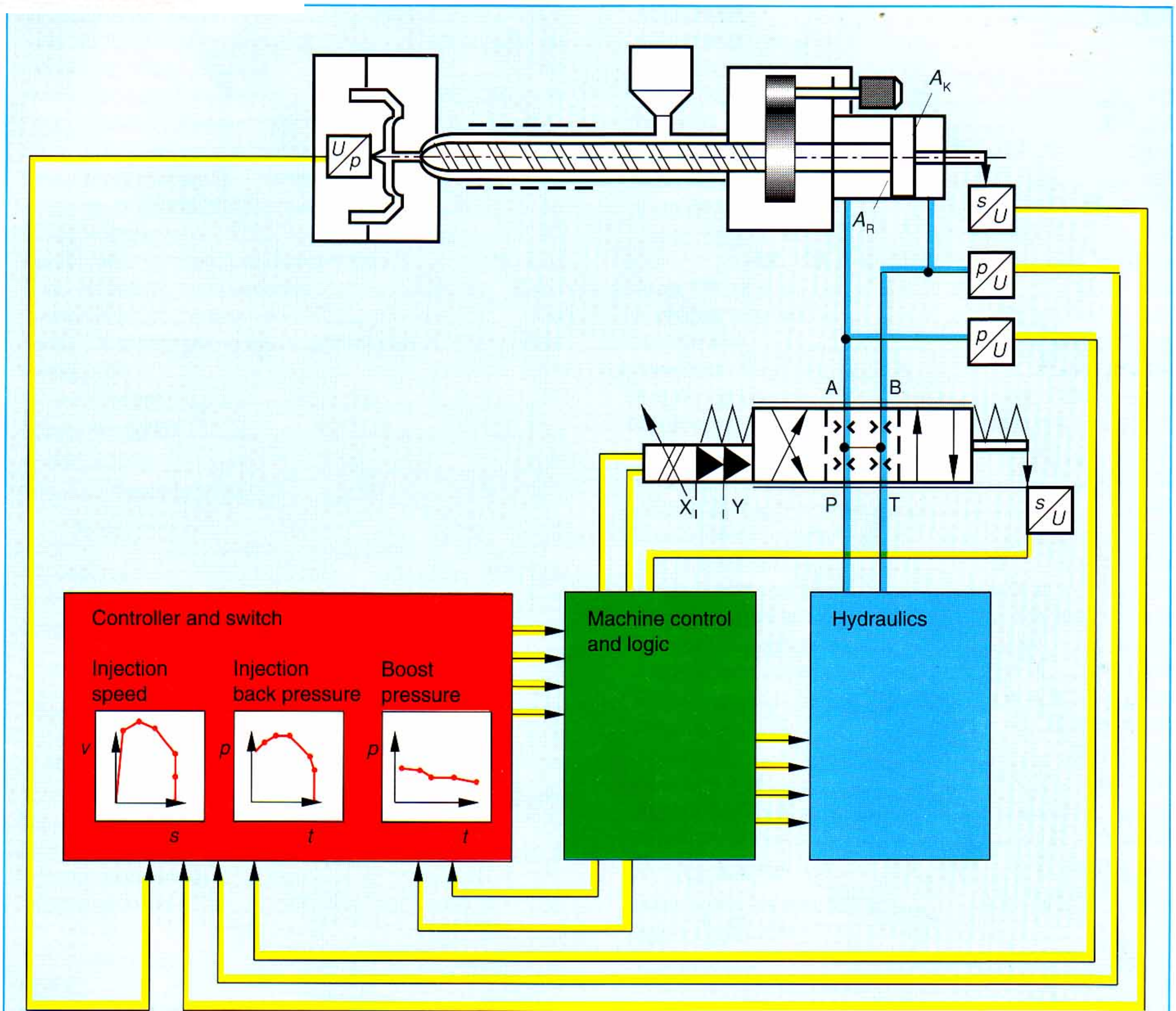
The actual value produced in this way is compared with the command signal of the injection curve and hence corrected.

When internal pressure measurement is used, the pressure inside the mould can be made to conform very accurately to a preset back pressure curve (during injection or forming) independently of the viscosity of the melt.

Changing from closed loop speed control to closed loop pressure control may occur either dependent on the "injection stroke" or dependent on the "mass/internal pressure".

The boost pressure during plastification also follows a curve based on process data.

All closed loop control procedures are implemented by proportional directional valve, 4 WRDE 52 V. The closed loop control electronics is based on microprocessor technology. The analogue regulator for the valve is designed in the form of a hardware regulator.



Technical Data

Injection cylinder

D = 560 mm

d = 250 mm

H = 480 mm

v_{min} = 2 mm/s

v_{max} = 135 mm/s

Q_{min} = 1900 L/min

Q_{max} = 30 L/min

p_{min} = 5 bar

p_{max} = 140 bar

$\mathbf{F = p_K \cdot A_K - p_R \cdot A_R}$

F_{max} = 3500 kN

Fig. 296