



湖南恒石液压技术有限公司
HONSFUID · HYDRAULICS TRAINING

液压基础入门培训

Hydraulics Fundamentals

$$Q = C_d A \sqrt{(2\Delta p/\rho)}$$

开口面积 × 压差平方根

Area × square root of pressure difference

湍流孔口近似 / Turbulent orifice approximation

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本次培训的学习目标

Learning objectives

01 理解压力、流量和功率

Explain pressure, flow rate and hydraulic power.

02 认识泵、阀、缸、马达及辅助元件

Identify pumps, valves, cylinders, motors and accessories.

03 沿着油路解释一个基本动作

Trace the oil path for a basic machine movement.

04 掌握检查顺序和基本安全要求

Follow a basic inspection sequence and safety precautions.

液压在设备中的作用

Hydraulics in everyday machinery



用液体传递能量，驱动负载运动

A liquid transmits energy to move a load.

油缸完成举升、伸缩与夹紧

Cylinders provide lifting, extension and clamping.

马达完成回转、行走与绞盘驱动

Motors drive rotation, travel and winches.

液压系统的五类组成

Five groups in a hydraulic system

类别 / Group	典型元件 / Examples	主要作用 / Function
动力 / Power supply	液压泵 / Pump	机械能转为液压能 Mechanical to hydraulic energy
执行 / Actuation	缸、马达 / Cylinder, motor	产生运动与力或转矩 Motion, force or torque
控制 / Control	方向、压力、流量阀 Direction, pressure, flow valves	控制动作与保护系统 Control motion and protect
辅助 / Accessories	油箱、过滤器、管路 Tank, filters, lines	储油、净化与连接 Storage, filtration, connection
介质 / Fluid	液压油 / Hydraulic fluid	传能、润滑、冷却 Power transfer, lubrication, cooling

帕斯卡原理与力的放大

Pascal's principle and force multiplication

$$p = F / A$$

同一静止连通液体，同一高度处的压力相同

Pressure is equal at the same elevation in a connected fluid at rest.

小活塞：100 N ÷ 1 cm²

Small piston: pressure = 1 MPa

大活塞：1 MPa × 10 cm² = 1,000 N

Large piston: ten times the area gives ten times the force.

理想计算，忽略摩擦、泄漏及回油背压 / Ideal calculation, losses ignored

压力与流量的区别

Pressure and flow rate

p

压力：推动负载所需的“力度”

Pressure: the effort needed to overcome a load.

面积相同时，压力影响推力

With the same area, pressure affects force.

Q

流量：每分钟输送多少油

Flow rate: the volume of oil delivered per minute.

面积相同时，流量影响速度

With the same area, flow rate affects speed.

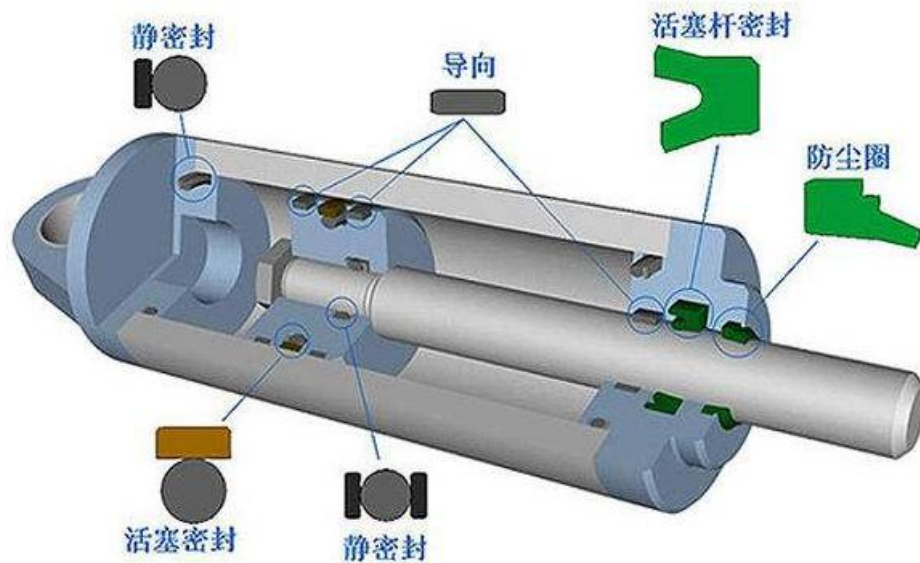
入门常用单位

Common units

物理量 / Quantity	常用单位 / Unit	记忆方法 / Reminder
压力 / Pressure	MPa、bar	1 MPa = 10 bar
流量 / Flow rate	L/min	每分钟的油液体积 Fluid volume per minute
排量 / Displacement	cm ³ /rev	每转的理论油液体积 Theoretical volume per revolution
力与转矩 / Force, torque	N、kN、N·m	1 kN = 1,000 N
功率 / Power	kW	1 kW = 1,000 W

液压缸的结构

Hydraulic cylinder anatomy



缸筒、活塞和活塞杆

Barrel, piston and piston rod form the moving assembly.

无杆腔与有杆腔

Cap end and rod end have different effective areas.

密封防止泄漏，导向件承受侧向支撑

Seals limit leakage. Guide rings support alignment.

常见液压缸类型

Common cylinder types

类型 / Type	动作特点 / Motion	典型用途 / Application
单作用缸 Single acting	一侧供油，外力返回 Hydraulic motion in one direction	举升、顶升 Lifting and jacking
双作用缸 Double acting	两腔交替供油 Either chamber receives pressure	伸缩、推拉 Extension and retraction
伸缩缸 Telescopic	多级套筒，长行程 Multiple stages, long stroke	自卸车举升 Dump body lifting
摆动执行器 Rotary actuator	有限角度的往复摆动 Rotation over a limited angle	翻转、定位 Tilting and positioning

油缸的推力与速度

Cylinder force and speed

$$F \approx p \times A \quad v \approx Q / A$$

同一油缸，压力影响推力，进入腔的流量影响速度

For a given cylinder, pressure affects force and inlet flow affects speed.

实际推力还受另一腔背压和摩擦影响

Opposing pressure and friction reduce available force.

相同流量下，面积越大，速度越低

With the same flow, a larger area produces a lower speed.

算例：伸出推力与速度

Worked example: extension

$$D = 50 \text{ mm} \quad p = 10 \text{ MPa} \quad Q = 12 \text{ L/min}$$

$$\text{无杆腔面积 } A = \pi D^2 / 4 \approx 1,963 \text{ mm}^2$$

$$\text{Cap-end area } A \approx 1,963 \text{ mm}^2 = 0.001963 \text{ m}^2.$$

$$\text{理论推力 } F \approx 19.6 \text{ kN}$$

$$F = 10 \text{ N/mm}^2 \times 1,963 \text{ mm}^2$$

$$\text{理论速度 } v \approx 0.102 \text{ m/s}$$

$$Q = 0.0002 \text{ m}^3/\text{s}, \text{ so } v = Q / A.$$

理想计算，忽略摩擦、泄漏及回油背压 / Ideal calculation, losses ignored

伸出与缩回的差异

Extension and retraction

$$A_{rod} = \pi(D^2 - d^2) / 4$$

单杆缸的有杆腔有效面积更小

A single-rod cylinder has a smaller effective area at the rod end.

D = 50 mm, d = 30 mm

Rod-end area $\approx 1,257 \text{ mm}^2$

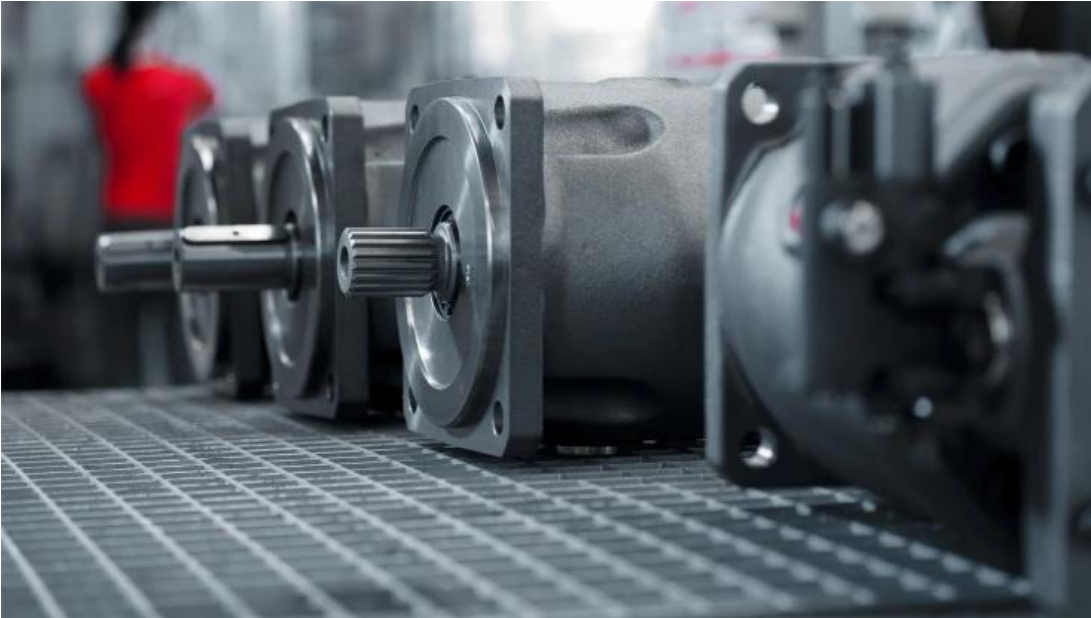
同压同流：缩回力较小，速度较快

At 10 MPa and 12 L/min: 12.6 kN and 0.159 m/s.

理想计算，忽略摩擦、泄漏及回油背压 / Ideal calculation, losses ignored

液压泵如何输送油液

How a hydraulic pump moves oil



封闭工作腔周期性改变容积

Sealed working chambers repeatedly change volume.

容积增大吸油，容积减小排油

Increasing volume draws oil in. Decreasing volume expels it.

吸油与排油区需要相互隔开

Inlet and outlet zones need separation.

排量、转速与流量

Displacement, speed and flow

$$Q \approx Vg \times n \times \eta_v / 1,000$$

Vg: cm³/rev, n: r/min, Q: L/min

Vg is displacement, n is shaft speed, and η_v is volumetric efficiency.

例: 20 cm³/rev × 1,500 r/min

Theoretical flow = 30 L/min

若 $\eta_v = 0.90$, 实际流量约 27 L/min

At 90% volumetric efficiency, flow is about 27 L/min.

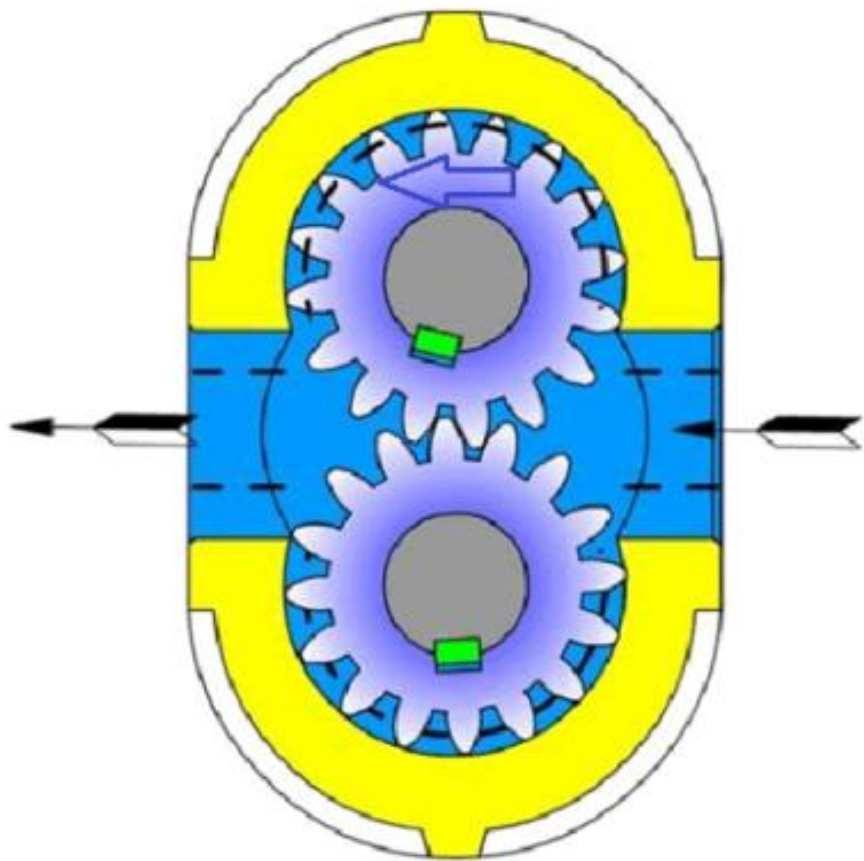
齿轮泵、叶片泵与柱塞泵

Gear, vane and piston pumps

类型 / Type	基本特点 / Typical traits	入门关注点 / What to notice
齿轮泵 / Gear	结构较简单，常见定量型 Simple construction, often fixed	转向、吸油口与排量 Rotation, inlet and displacement
叶片泵 / Vane	叶片分隔工作腔，运行较平稳 Vaness form chambers, smooth flow	吸油条件与油液清洁度 Inlet conditions and cleanliness
柱塞泵 / Piston	适用高压，可实现变量控制 High-pressure duty, variable options	变量控制与壳体泄油 Displacement control and drain

齿轮泵的基本原理

Gear pump fundamentals



齿轮转动，齿间容积携带油液

Rotating gears carry oil in the spaces between teeth.

油液沿壳体外侧送到排油区

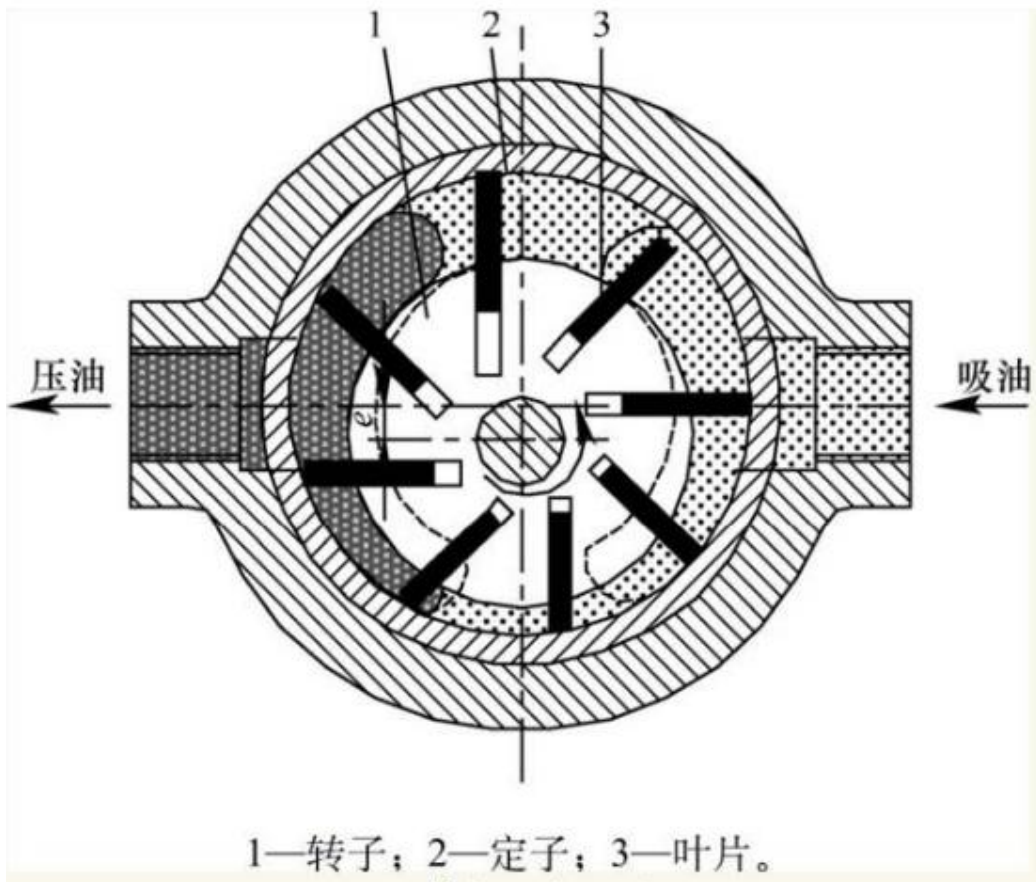
Oil travels around the housing to the outlet.

啮合区把吸油侧与排油侧隔开

The meshing zone separates inlet and outlet.

叶片泵与柱塞泵

Vane and piston pumping mechanisms



叶片泵：叶片与定子围成工作腔

Vane pump: vanes and the stator form chambers.

柱塞泵：柱塞往复改变工作腔容积

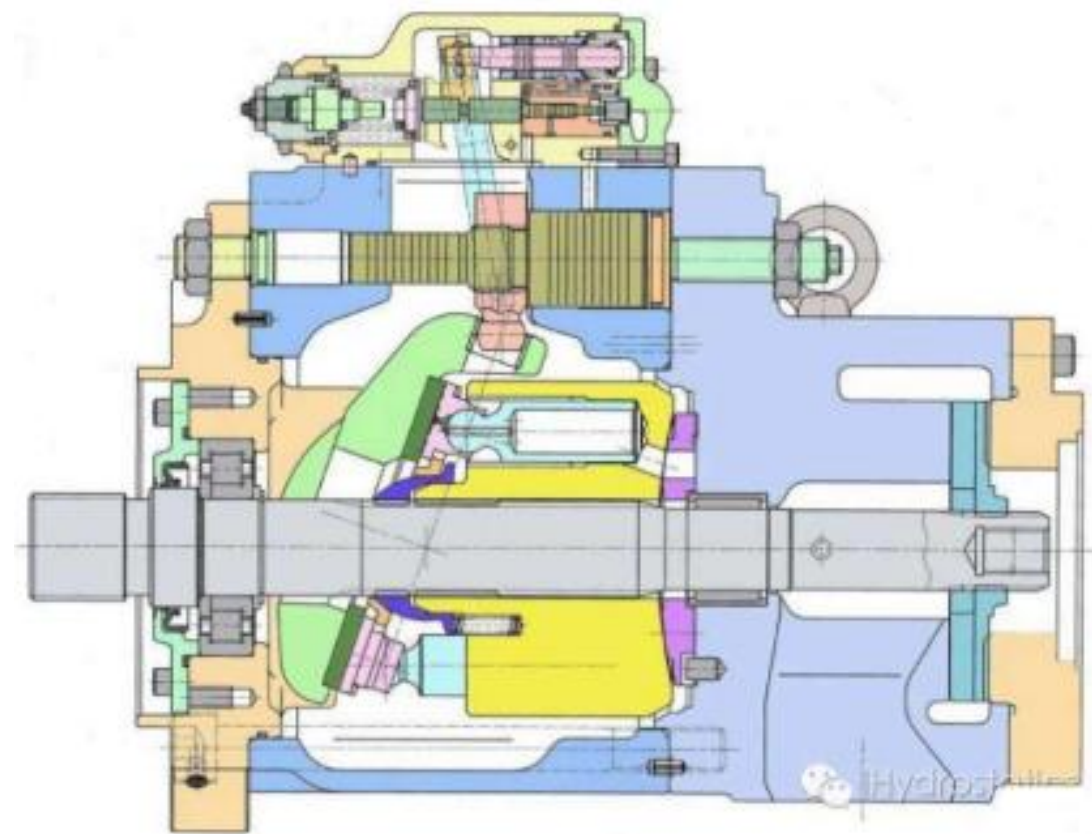
Piston pump: reciprocating pistons change chamber volume.

变量泵可改变每转排量

A variable pump changes displacement per revolution.

轴向柱塞泵的结构示例

Axial piston pump example



柱塞随缸体旋转并往复运动

Pistons rotate with the barrel and reciprocate.

斜盘倾角影响柱塞行程与排量

Swashplate angle affects piston stroke and displacement.

吸油、排油与泄油口功能不同

Inlet, delivery and case-drain ports serve different functions.

液压马达的基本认识

Hydraulic motor fundamentals

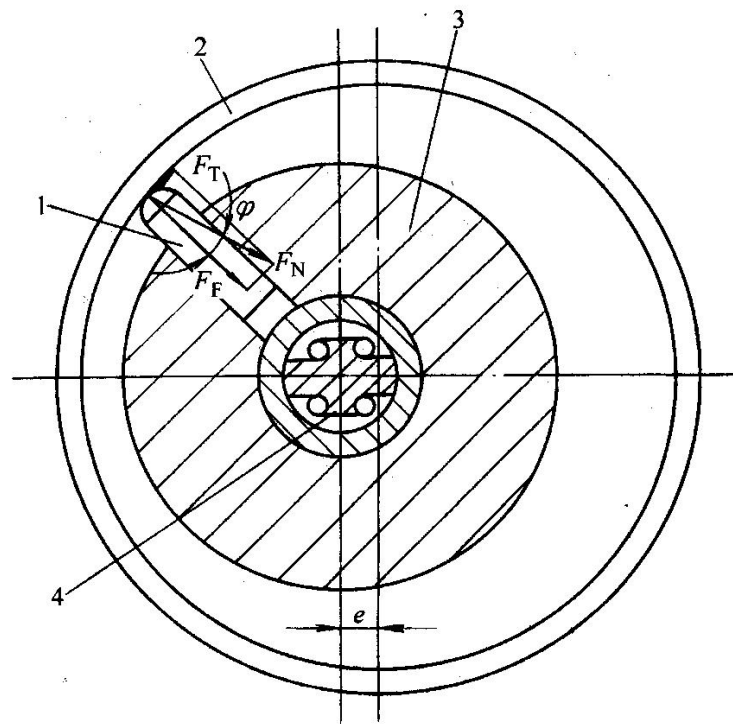


图 3-2 径向柱塞马达工作原理

1—柱塞 2—马达 3—缸体 4—配油轴

马达把液压能转为回转运动

A motor converts hydraulic energy into rotary motion.

流量影响转速，压差影响转矩

Flow affects speed. Pressure difference affects torque.

泵与马达原理互逆，型号不可随意替用

Pumps and motors reverse the energy conversion. Substitution requires approval.

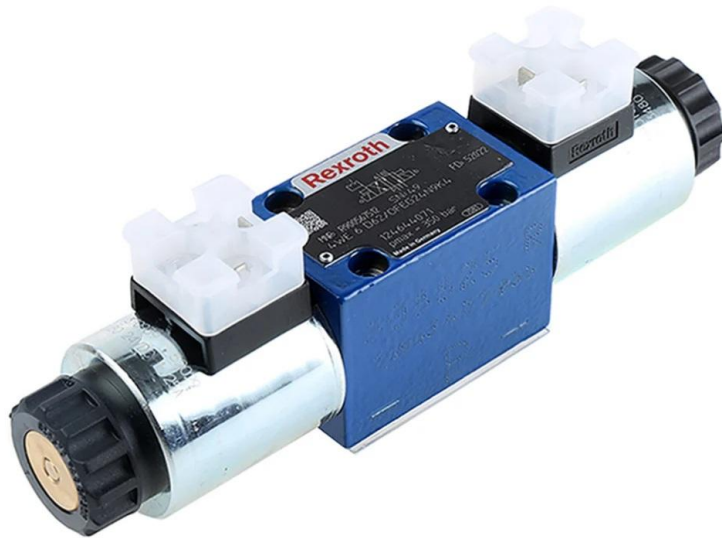
液压阀的三类功能

Three main valve functions

类别 / Category	解决的问题 / Purpose	常见元件 / Examples
方向控制 Directional control	去哪里，何时启停 Where oil flows, start and stop	换向阀、单向阀 Directional valve, check valve
压力控制 Pressure control	限压或调整支路压力 Limit or regulate pressure	溢流阀、减压阀、顺序阀 Relief, reducing, sequence valve
流量控制 Flow control	调节执行元件速度 Adjust actuator speed	节流阀、调速阀 Throttle, compensated flow valve

换向阀与主油口

Directional valves and main ports



P 接供油, T 接回油

P is the pressure supply. T is the tank return.

A、B 接执行元件的两个工作口

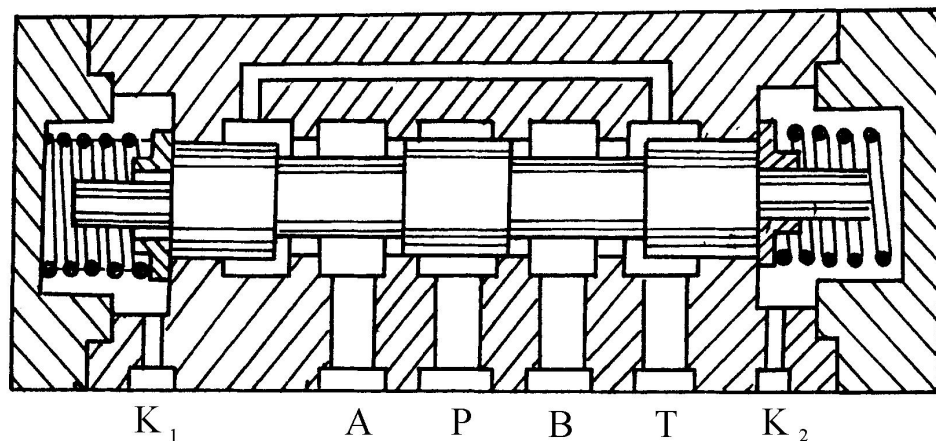
A and B connect to the actuator work ports.

电磁铁或手柄改变阀芯位置

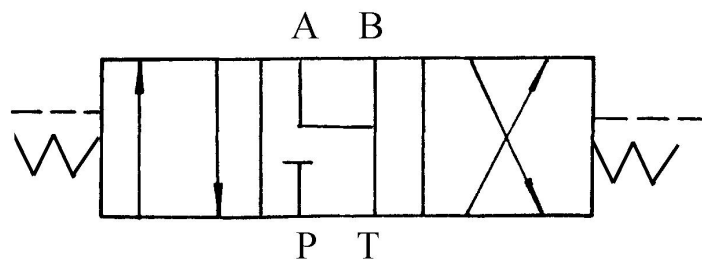
Solenoids or a lever move the spool.

换向阀符号中的“位”与“通”

Positions and ports in a valve symbol



(a)



(b)

每个方框代表一个工作位置

Each square represents a spool position.

三位四通：3 个位置、4 个主油口

A 4/3 valve has four main ports and three positions.

线表示连通，堵头表示截止

Lines indicate connections. A blocked end indicates closure.

常见中位连接方式

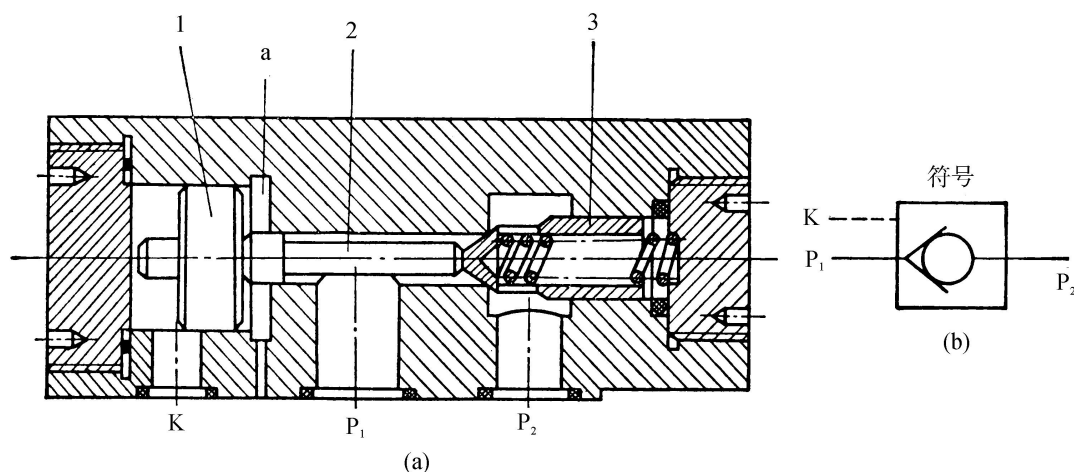
Common center connections

中位连接 / Center condition	泵侧 / Pump side	执行元件侧 / Actuator side
全封闭 / All ports blocked	P 口封闭 Supply blocked	A、B 封闭 Work ports blocked
P 通 T, A、B 封闭 Tandem center	泵流量可回油箱 Pump flow returns to tank	工作口封闭 Work ports blocked
A、B 通 T, P 封闭 Float center	P 口封闭 Supply blocked	允许负载带动运动 Load may move the actuator

工作口封闭不等同安全锁紧 / Closed ports do not guarantee safe load holding

单向阀与液控单向阀

Check and pilot-operated check valves



普通单向阀允许单向流动

A check valve allows flow in one direction.

液控单向阀由先导压力打开反向通路

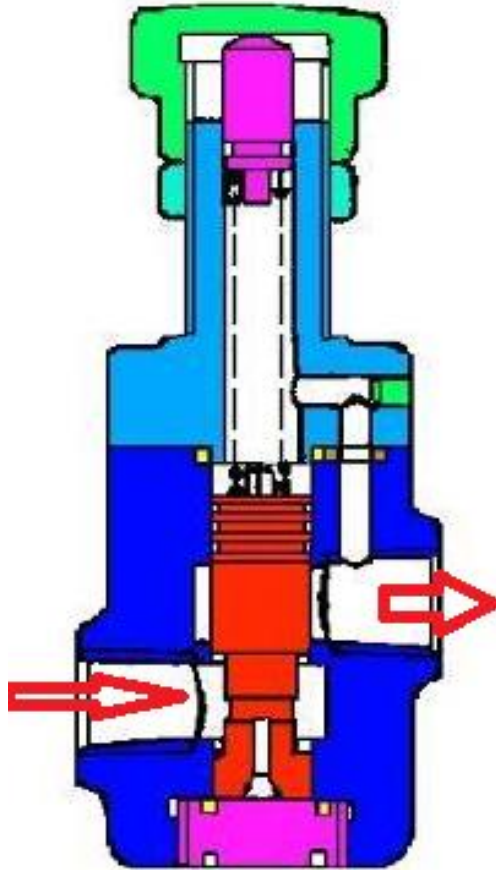
Pilot pressure opens the reverse path in a pilot-operated check.

需要平稳下降时还要考虑负载控制阀

Controlled lowering may require a load-control valve.

溢流阀的限压作用

Pressure relief valve



压力达到设定条件时，油液流回油箱

Oil returns to tank when the opening pressure is reached.

常用于限制最高工作压力

A relief valve commonly limits operating pressure.

长期溢流会把能量转为热量

Continuous relief flow turns hydraulic energy into heat.

溢流阀与减压阀

Relief and pressure reducing valves

比较项 / Item	溢流阀 / Relief valve	减压阀 / Reducing valve
关注压力 Controlled pressure	阀前压力 Upstream pressure	阀后压力 Downstream pressure
基本任务 Main purpose	限制上游压力，向油箱泄放 Limit pressure by diverting flow	给支路提供较低压力 Provide lower branch pressure
常见例子 Typical example	系统限压保护 System pressure limiting	夹紧或先导油路 Clamping or pilot supply

顺序阀与压力信号

Sequence valves and pressure signals

01 顺序阀：达到压力条件后接通另一支路

A sequence valve opens another branch at a pressure threshold.

02 压力开关：把压力条件变成电信号

A pressure switch converts a pressure threshold into an electrical signal.

03 压力传感器：连续输出压力测量值

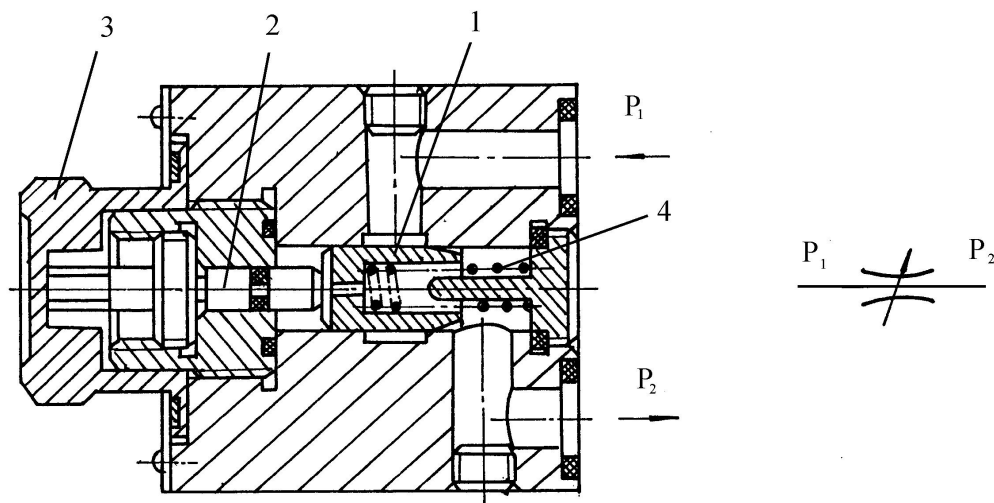
A pressure transducer provides a continuous pressure measurement.

04 压力到位不代表机械位置一定到位

Reaching pressure does not prove the actuator reached its intended position.

节流阀与调速阀

Throttle and compensated flow control



改变阀口大小，可以调节流量

Changing the opening adjusts flow rate.

普通节流阀的流量会随压差变化

Flow through a simple throttle changes with pressure difference.

调速阀在工作范围内补偿压差变化

A compensated flow valve reduces the effect of pressure changes.

图示为普通节流阀 / Illustration: a simple throttle valve

节流口的核心流量公式

The core orifice flow equation

$$Q = C_d A \sqrt{(2\Delta p / \rho)}$$

A 是开口截面积， Δp 是孔口两端的压差

A is the opening area. Δp is the pressure difference across the orifice.

开口面积增加到 2 倍，流量约为 2 倍

At fixed Δp , C_d and density: doubling A doubles Q.

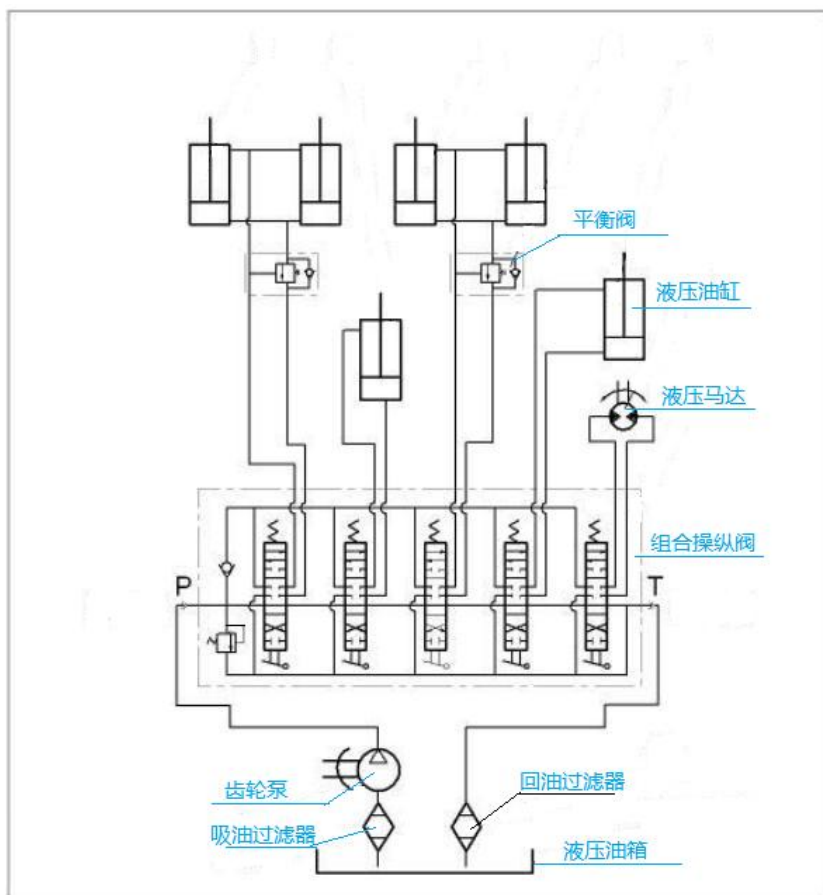
压差增加到 4 倍，流量约为 2 倍

At fixed A, C_d and density: quadrupling Δp doubles Q.

C_d : 流量系数 / discharge coefficient ρ : 密度 / density

沿着一个支路读回路

Tracing one branch of a circuit



先找油箱、泵和系统限压元件

Locate the tank, pump and pressure limiting element.

选择一个阀位，追踪到执行元件

Choose a valve position and trace flow to an actuator.

再追踪另一腔的回油路径

Then trace the return path from the opposite chamber.

双作用缸的伸出、停止与缩回

Extension, stop and retraction

01 伸出：P 接无杆腔，有杆腔接 T

Extension: supply to the cap end, rod end returns to tank.

02 停止：中位机能决定油口连接和泵的状态

Stop: center connections determine actuator and pump conditions.

03 缩回：P 接有杆腔，无杆腔接 T

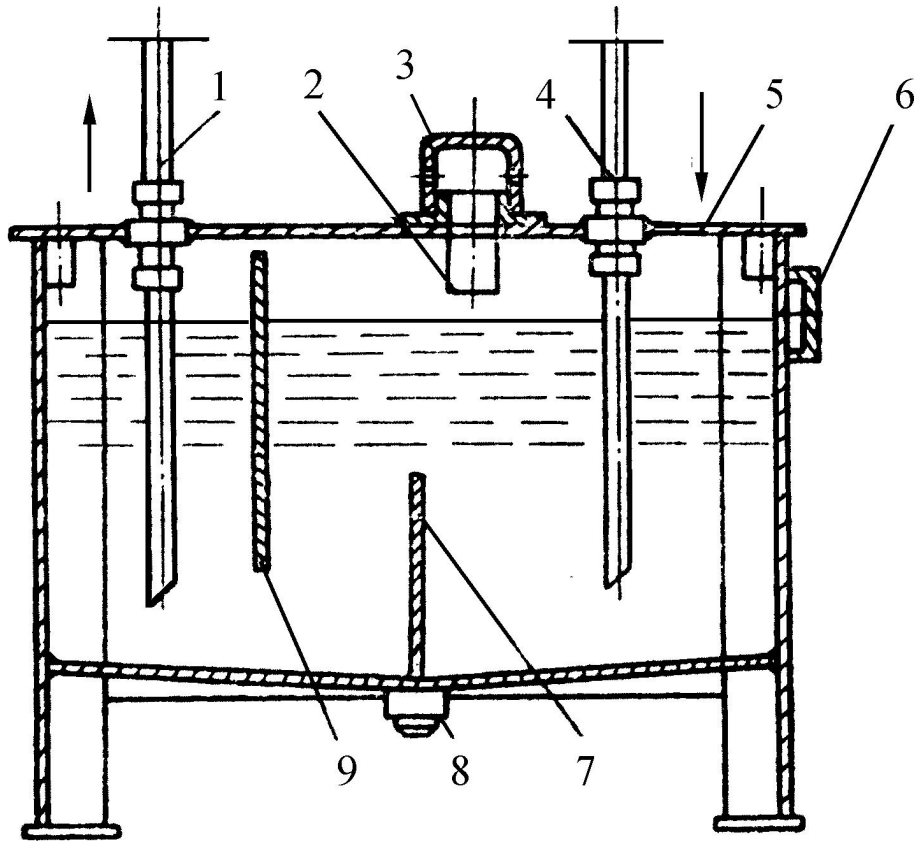
Retraction: supply to the rod end, cap end returns to tank.

04 持载：根据负载配置专用保护和锁紧措施

Load holding: provide suitable valves and mechanical protection.

油箱与辅助元件

Reservoir and accessories



油箱储油，并帮助散热与空气分离

The reservoir stores oil and supports cooling and air separation.

呼吸器、液位计和温度计辅助检查

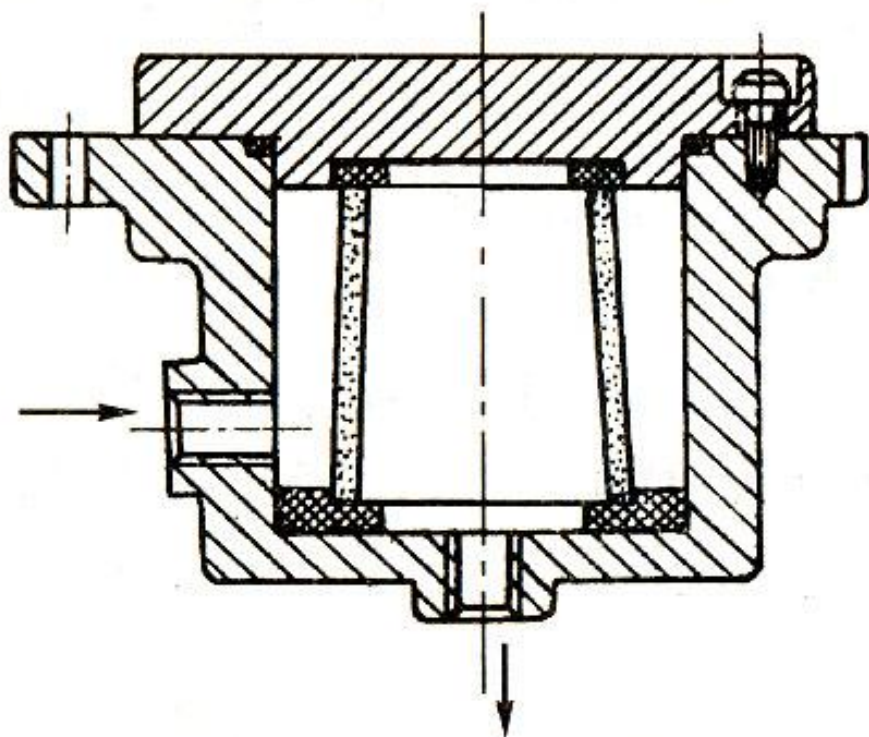
Breather, level indicator and thermometer aid inspection.

管路、冷却器和密封件也影响可靠性

Lines, coolers and seals also affect system reliability.

过滤器与油液清洁度

Filtration and fluid cleanliness



污染会磨损元件、堵塞小孔和卡滞阀芯

Contamination can cause wear, blocked passages and sticking valves.

新油也可能需要过滤后加入

New oil may require filtration before filling.

检查堵塞指示，按要求更换滤芯

Check the clogging indicator and replace elements as specified.

液压油与黏度等级

Hydraulic fluid and viscosity grade

关注项 / Item	基本含义 / Meaning	正确做法 / Action
黏度 / Viscosity	过稠增加吸油阻力，过稀增加泄漏 Too thick impedes inlet flow, too thin increases leakage	按温度和元件要求选择 Match temperature and components
ISO VG 46	40°C 时名义运动黏度约 46 mm ² /s Nominal viscosity near 46 mm ² /s at 40°C	数字不是允许最高温度 The number is not a temperature limit
HM、HV 等类别 Fluid category	反映抗磨等性能类别 Describes fluid performance	确认规格与相容性 Confirm specification and compatibility

蓄能器与停机后的能量

Accumulators and stored energy

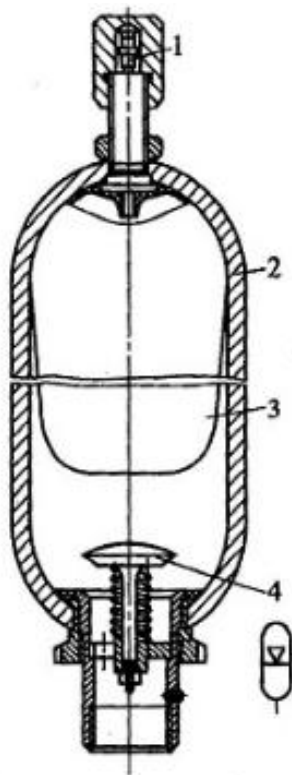


图 B 气囊式蓄能器

1—充气阀；2—壳体；3—气囊；4—菌形限位阀

压缩气体储存能量，需要时释放油液

Compressed gas stores energy and releases fluid when needed.

可用于补油、应急供能和吸收脉动

Applications include make-up flow, emergency energy and pulsation damping.

停泵后仍可能有压力，维护前须隔离泄压

Pressure may remain after shutdown. Isolate and depressurize before service.

液压功率与发热

Hydraulic power and heat

$$P_h(\text{kW}) = p(\text{MPa}) \times Q(\text{L/min}) / 60$$

例：10 MPa × 12 L/min = 2 kW 液压功率

Example: 10 MPa at 12 L/min delivers 2 kW of hydraulic power.

实际驱动功率还要计入效率损失

Required drive power is higher because of losses.

流量经压差节流或溢流时会发热

A pressure drop across a throttle or relief path produces heat.

安全操作的基本要求

Basic hydraulic safety

01 停止并隔离动力，支撑负载，释放残余压力

Stop and isolate power, support loads and release stored pressure.

02 泄漏检查使用规定工具，手远离高压喷流

Use approved inspection methods. Keep hands away from fluid jets.

03 高压液体注入皮肤后，立即接受急诊处理

Seek emergency medical treatment immediately after a fluid injection injury.

04 检修、充氮和调压由受训人员按程序进行

Trained personnel must follow approved service, charging and setting procedures.

压力表为零仍需确认封闭腔残压 / Verify trapped pressure even if one gauge reads zero

开机前的基础检查

Basic checks before starting

01 油液：型号、液位、温度与异常外观

Fluid: grade, level, temperature and abnormal appearance.

02 连接：管路、接头、泄油管 and 防护

Connections: hoses, fittings, case drains and guards.

03 状态：阀位、急停与人员所在位置

State: valve position, emergency stop and personnel clearance.

04 按设备程序低负载启动，记录压力、声音与动作

Start under low load as specified. Record pressure, noise and motion.

常见现象与排查方向

Symptoms and initial checks

现象 / Symptom	可能方向 / Possible causes	先观察 / Initial observations
动作慢 / Slow motion	流量不足、泄漏、节流限制 Low flow, leakage, restriction	转速、阀位、温度 Speed, valve state, temperature
力不足 / Low force	压力不足、背压、负载过大 Low pressure, back pressure, high load	两腔压力与负载 Both chamber pressures and load
噪声 / Noise	进气、吸油阻力、安装问题 Air entry, inlet restriction, mounting	油位、吸油管、起泡 Level, inlet line, foaming
发热 / Overheating	持续溢流、节流、冷却不足 Relief flow, throttling, poor cooling	负载、回油、冷却器 Load, return flow, cooler

四个常见误区

Four common misconceptions

常见说法 / Statement	正确理解 / Clarification
压力越高，速度一定越快 Higher pressure always means higher speed	速度主要与流量和有效面积有关 Speed mainly depends on flow and effective area
定量泵的流量永远不变 A fixed pump always delivers the same flow	固定的是排量，流量也受转速和泄漏影响 Displacement is fixed. Flow varies with speed and leakage
停机就可以拆管 Shutdown makes a line safe to disconnect	负载、蓄能器及封闭腔仍可能储能 Loads, accumulators and trapped volumes may retain energy
清澈的新油一定干净 Clear new oil must be clean	目测无法判断细小颗粒污染 Visual inspection cannot measure fine particle contamination

课堂小测验

Knowledge check

01 同一油缸想提高速度，应重点看压力还是流量？

For the same cylinder, which mainly affects speed: pressure or flow?

02 10 MPa 相当于多少 bar？

How many bar equal 10 MPa?

03 限制系统压力通常使用哪一类阀？

Which valve commonly limits system pressure?

04 停泵后，哪些位置还可能有压力？

Where might pressure remain after the pump stops?

小测验参考答案

Knowledge check answers

01 流量：面积一定时， $v \approx Q / A$

Flow rate: for a fixed area, $v \approx Q / A$.

02 10 MPa = 100 bar

10 MPa equals 100 bar.

03 溢流阀，设定值按批准资料确认

A relief valve, with its setting confirmed against approved data.

04 蓄能器、受载油缸和封闭油路

Accumulators, loaded cylinders and trapped circuit volumes.

常用中英文术语

Useful Chinese–English terminology

中文 / Chinese	English	中文 / Chinese	English
压力	Pressure	流量	Flow rate
排量	Displacement	背压	Back pressure
液压泵	Hydraulic pump	液压马达	Hydraulic motor
液压缸	Hydraulic cylinder	换向阀	Directional valve
溢流阀	Relief valve	减压阀	Pressure reducing valve
单向阀	Check valve	蓄能器	Accumulator

培训回顾

Training recap

01 压力与有效面积影响力，流量与面积影响速度

Pressure and area affect force. Flow and area affect speed.

02 泵供油，阀控制，缸和马达带动负载

The pump supplies oil, valves control it, actuators move the load.

03 读回路时同时追踪进油与回油

Trace both supply and return paths when reading a circuit.

04 清洁油液与安全隔离是基础工作

Clean fluid and safe isolation are essential.

资料来源与继续学习

Sources and further learning

01 基础资料：恒石液压原培训课件

Base material: the original HONSFUID course by David Wu.

02 原理与元件：Bosch Rexroth、Parker

Principles and components: Bosch Rexroth and Parker technical material.

03 过滤、油液与蓄能器：HYDAC、Shell

Filtration, fluids and accumulators: HYDAC and Shell.

04 安全：HSE 高压液体注入伤安全提醒

Safety: HSE guidance on high-pressure fluid injection.