Sample Course File

Basic Course Documents
(By-Law 2000)

Course Code: M578, Title: Hydraulic Power Systems

✓	Course Specifications
✓	Lecturers Resume
✓	Assistants Resume
✓	Lecture notes/text book
✓	Laboratory Book

✓=Document Exists x=Document doesn't exist NR=Not Relevant

Course Specifications

M578: Hydraulic Power Systems

A- Affiliation

Relevant program: Manufacturing Engineering and Production Technology BSc Program
Department offering the program: Mechanical Engineering Department
Department offering the course: Mechanical Engineering Department
Date of specifications approval: September 2015

B - Basic information

Title: Hydraulic Power System	**Code:** M578	**Year/level:** Fifth/first Semester
Teaching Hours:	**Lectures:** 3	**Tutorial:**2
	Practical: 2	**Total:** 7

C - Professional ~~information~~

1 – Course Learning Objectives:

By the end of this course the students should demonstrate the knowledge and understanding of the construction and operation of hydraulic power systems and their basic elements. They should be able to operate, maintain, design, calculate and analyze the performance of hydraulic power systems and their basic components.

2 - Intended Learning Outcomes (ILOS)

a - Knowledge and understanding:

On successful completion of the course, the student should demonstrate knowledge and understanding of:

a1- Classification and specifications of power systems (A3, A8)
a2- Theoretical background needed to calculate and analyze the characteristics of the hydraulic systems and their components (A1, A2).
a3- Basic properties of hydraulic fluids and their effect on the system performance (A3)
a4- Construction, operation and characteristics of the basic components of hydraulic power systems; pumps, valves, actuators, transmission lines and accessories (A3, A3)).
a5- Standard symbols of hydraulic power systems (A3)
a6- Procedures of design of the hydraulic systems using industrial elements(A4,A5)
a7- Computer software related to hydraulic power systems design, calculation and animation (A1, A4).

b - Intellectual skills:

On successful completion of the course, the student should be able to.

b1- Investigate the effect of hydraulic fluid properties on the function of hydraulic power systems (B1, B13)
b2- Deduce mathematical relations describing the steady state performance of hydraulic power systems and their elements and select the proper methods for their solution (B1, B2, B13)
b3- Analyze the static characteristics of hydraulic power systems and their components (B5, B9, B14)
b4- Classify and compare the different ways of hydraulic elements connection (B2,B5,B15).

c - Professional and practical skills:

On successful completion of the course, the student should be able to:

c1- Design, assemble, operate, test and maintain simple hydraulic system (C1,C3)
c2- Calculate the steady state characteristics of hydraulic systems and their subsystems and basic components and (C1, C5).
c3- Use computer software; Automation Studio, Marex and other available programs to design, calculate, simulate or animate hydraulic power systems and their components (C5).
c4- Solve limited operational problems related to the hydraulic power systems and their basic elements (C1, C5,C6).
c5- Use experimental facilities to visualize and investigate the cavitation phenomenon and evaluate the characteristics of typical roto-dynamic and displacement pumps (C12, C16, C17).
c6- Use experimental facilities to assemble and operate diverse hydraulic circuits (C17).

d - General and transferable skills:

On successful completion of the course, the student should be able to:

d1- Work in a team and involve in group discussion and seminars (D1, D3).

d2- Communicate effectively and present data and results orally and in written form (D3).

d3- Use ICT facilities in presentations (D4).

d4- Search for information's in references and in internet (D7).

d5- Practice self-learning (D7, D9).

Course Contribution in the Program ILO's

ILO's		Program ILO's
A	Knowledge and understanding	A1, A2, A3, A4, A5, A8
B	Intellectual skills	B1, B2, B5, B9, B13, B14, B15
C	Professional and practical skills	C1, C3, C5, C6, C12, C16, C17
D	General and transferable skills	D1, D3, D4, D7, D9

3 - Contents

Topic	Lecture hours	Tutorial hours	Practical hours
➢ Power systems, classification, operation, and comparison.	2		
➢ Introduction to hydraulic power systems and standard symbols	2	2	2
➢ Hydraulic fluids; properties and their effect on the system performance.	4	2	2
➢ Hydraulic transmission lines and connectors	2	2	2
➢ Hydraulic pumps:		4	4
• Classification and basic mathematical relations	2		
• Gear pumps, vane pumps and piston pumps	4		
• Fixed and variable displacement pumps and pump control	2	2	2
➢ Control valves		2	2
• Classification and basic design	2		
• Pressure control valves (direct/pilot operated); relief valves, pressure reducers, sequence valves and accumulator charging valves	4	2	2
• Directional control valves	2	2	2
• Flow control valves	2		
• Check valves	2		
➢ Hydraulic actuators; cylinders, motors and rotary actuators	2	2	2
➢ Accessories; accumulators, filters, reservoirs, pressure switches,…etc	2	4	2
➢ Case studies; design and analysis of function of hydraulic circuits of industrial and mobile systems.	2		6
➢ Mini project; design and analysis of the hydraulic system for an industrial application. Analysis of the possible operational problems...	6	4	2
➢ Seminar	3	2	
Total hours	**45**	**30**	**30**

4 - Teaching and Learning and Assessment methods:

Course ILO's		Teaching Methods						Learning Methods		Assessment Method				
		Lecture	Presentations & Movies	Discussions & seminars	Tutorials	Problem solving	Laboratory & Experiments	Researches & Reports	Modeling and Simulation	Written Exam	Practical Exam	Quizzes	Term papers	Assignments
Knowledge & Understa	a1	1	1	1	1		1	1		1		1	1	
	a2	1			1					1		1	1	1
	a3	1			1					1		1	1	1

	a4	1	1	1	1	1	1	1		1		1	1	1
	a5	1					1			1	1	1	1	1
	a6	1						1					1	1
	a7	1		1	1	1		1	1				1	
Intellectual Skills	b1	1			1					1		1		1
	b2	1			1	1				1		1	1	1
	b3	1	1	1	1		1	1		1	1		1	
	b4	1	1		1		1	1		1	1	1	1	1
Applied Professional Skills	c1	1	1		1	1	1			1	1	1	1	1
	c2	1			1					1		1	1	1
	c3	1		1		1		1	1				1	1
	c4	1			1	1					1		1	1
	c5						1				1			
	c6						1				1			
General Tran. Skills	d1			1		1		1					1	
	d2		1	1				1	1				1	
	d3	1	1					1					1	1
	d4	1	1	1				1						
	d5							1	1				1	

5- Assessment Timing and Grading:

Assessment Method	Timing	Grade (Degrees)
Semester Work: seminars, quizzes assignments and reports	Bi-Weekly	15
Mid-Term Exam	6-th Week	15
Practical Exam	Fifteenth week	20
Written Exam	Sixteenth week	100
Total		150

6- List of references:

6-1 Course notes: Non

6-2 Required books

M Galal Rabie, Fluid Power Engineering, McGraw-Hill. NY, 2009

6-3 Recommended books: Non

- **M Galal Rabie**, Automatic Control for Mechanical Engineers, ISBN 977-17-9869-3, 2010
- **Ibrahim Saleh and M Galal Rabie,** Fluid Mechanics for Engineers, ISBN 978-977-5092-00-7, 2011

6-4 Periodicals, Web sites, etc.

http://www.moog.com/,
http://www.boschrexroth.com/en/xc/,
http://www.norgren.com/global/
http://www.eaton.com/Eaton/index.htm
http://www.nfpa.com/

7- Facilities required for teaching and learning:

- Fluid Power Lab.
- Computer, Data show and Computer programs; Automation studio, Marex, Rexroth hydraulic trainer, Rexroth hydraulic element animation and TK-Solver.

Course coordinator: Prof. Dr. M Galal Rabie
Head of the Department: Dr. Abdelmegid Abdellatif
Date: September 2015

Lecturers Resume

أستاذ دكتور / محمود جلال الدين محمد ربيع؛ قائم بأعمال وكيل الأكاديمية للتعليم والطلاب

Name: Mahmoud Galal El-Din Mohamed RABIE
Birth date and place: April 19, 1946, Dakahlia, Egypt
Email: Galalrabie@hotmail.com
Telephone: +20100 2211546
Address: 33 A Elbably st., 11331, Hadayek Elkobbah, Cairo, Egypt
Education:

PhD **Specialization:** Applied Computing and Automation Systems for Industry and Management
Awarded by: Claude Bernard University Lyon 1 and INSA, Lyon, France, Oct. 1980

Diploma **Specialization:** (DEA) Mechanical Engineering
Awarded by: Claude Bernard University Lyon 1, France, Nov., 1978

MSc **Specialization:** Mechanical Engineering
Awarded by: Military Technical College, Cairo, Egypt, Jan. 1977

BSc **Specialization:** Mechanical Engineering (Aircraft Engines)
Awarded by: Military Technical College, Cairo, Egypt, April, 1968

Positions Occupied and work experience

- Professor of Mechanical Engineering, Military Technical College (MTC), Nov. 1991
- Head of the Aircraft Mechanical Dpt.; MTC, Head of the Specialized Mechanical Engineering Branch, MTC, Chairman of the Scientific Council of the Aeronautical Department; MTC, Member of the Scientific Committee and Scientific Council of the MTC, up to January, 2005
- Profound experience in the vocational training and technical consultations in fluid power.
- Rapporteur general of the international conferences on Aerospace Sciences and Aviation Technology; ASAT-6, ASAT-7, ASAT-8 and ASAT-9, organized by the MTC, Cairo, Egypt.
- Cooperation with the National Authority for Quality Assurance and Accreditation in Education, NAQAAE, (2008-2009); Member of the High Committee for Higher Education, 2008 up-till now

Post graduate activities:

- Supervised 6 PhD and 29 MSc thesis.
- Member of examination board and jury for MSc & PhD examinations and thesis in the faculties of engineering of Cairo, Ain-Shams, Alexandria, Zagazig, Al-Azhar and Helwan Universities, the Military Technical College, Cairo and Beihang Univ., Beijing, China..

Published Papers:
Author and co-author of 68 scientific papers, published in refereed national and international journals and conferences.

Lectured Courses:
M201, M399, M482, M578, M599, MNF311, MNF413, MNF522, MNF537, MNF361,MNF362, MNF461, MNF561, -MNF563.

Authored books:

- **M Galal Rabie,** Fluid Power Engineering, McGraw-Hill, NY, USA, May 18, 2009.
- **M Galal Rabie,** Fluid Power Engineering, McGraw-Hill, NY, USA, (Korean Language Edition), 2012, ISBN-13: 9788996621102
- **M Galal Rabie**, Automatic Control for Mechanical Engineers, ISBN 977-17-9869-3, 2010
- **Ibrahim Saleh and M Galal Rabie,** Fluid Mechanics for Engineers, ISBN 978-977-5092-00-7, 2011
- **M Galal Rabie,** Introduction to Aeronautics, Printed lectures and web enabled ebook, Military Technical College, Cairo, 2011 (Lecture Notes).
- **M Galal Rabie, A Allam Elsenbawy, M Metwally and Tamer Nabil**, Aerospace Applications of Fluid Power, Printed Lectures, Military Technical College, Cairo, 2011 (Lecture Notes).

Current Institution:
Vice Dean of the Modern Academy for Engineering and Technology in Maadi, Cairo, Egypt.

Published Papers		Supervised Thesis	
During the last 5 years	Total	MSc Thesis	PhD Thesis
10	68	29	6

Assistants Resume

م.م / يحيى محمود عبد الوهاب حسن العطار

Name: Yahia Mahmoud Abdelwahab Hassan Elattar
Birth date and place: 25th January 1985, Sharkia, Egypt
Email: ymelattar@gmail.com
Telephone: 0100 45 75 155
Address: 54 Taqseem ElMesaha, Maadi, Cairo, Egypt

Education:

PhD **Specialization:** Mechanical Design and Production Engineering
Institution: Faculty of Engineering - Ain Shams University
(NOT COMPLETED / STILL ATTENDING)

MSc **Specialization:** Mechanical Design and Production Engineering
Awarded by: Faculty of Engineering - Cairo University
Thesis title: Modeling, Simulation and investigation of Vehicle Suspension and Design of Active Controllers

BSc **Specialization:** Manufacturing Engineering and Production Technology
Awarded by: Modern Academy for Engineering and Technology, Cairo, Egypt, 2007
Grade: Excellent with Honor Degree
Graduation project Grade: Excellent

POSITIONS OCCUPIED AND WORK EXPERIENCE

Position: Lecturer Assistant
From (Sep 2007) to (till now)
Institution: Mechanical Engineering Department, Modern Academy for Engineering & Technology

Teaches the following courses:

- Automatic Control
- Fluid Power Engineering – Hydraulics
- Machine Tool Design
- Engineering Economy
- Engineering Drawing
- Production Engineering – Workshop
- Modeling and Simulation
- AutoCAD (*summer training course*)

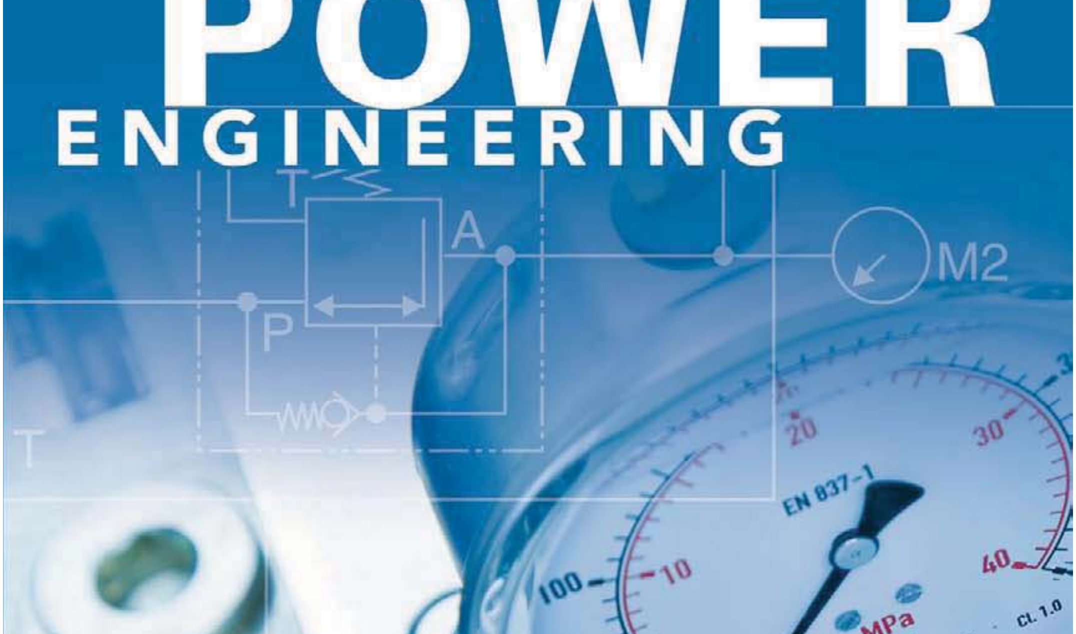
Publications

- Elattar Y. M., Rabie M.G., and Metwalli S.M., "On the Dynamics of Vehicle Passive Suspension Incorporating Twin-Tube Pressurized Shock Absorber", Proceedings of the *17th International Conference on Applied Mechanics and Mechanical Engineering, AMME-17*, MTC, Cairo, 2016
- Elattar Y. M., Metwalli S.M., and Rabie M.G., "PDF Versus PID Controller for Active Vehicle Suspension", Proceedings of the *17th International Conference on Applied Mechanics and Mechanical Engineering, AMME-17*, MTC, Cairo, 2016

Basic Reference

M Galal Rabie, Fluid Power Engineering, McGraw-Hill, NY, USA, May 18, 2009.

FLUID POWER ENGINEERING



M. GALAL RABIE

Fluid Power Engineering

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Fluid Power Engineering

M. Galal Rabie, Ph.D.
Professor of Mechanical Engineering
Modern Academy for Engineering and Technology
Cairo, Egypt

New York Chicago San Francisco
Lisbon London Madrid Mexico City
Milan New Delhi San Juan
Seoul Singapore Sydney Toronto

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To my wife Fatemah Rafat

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About the Author

M. Galal Rabie, **Ph.D.,** is a professor of mechanical engineering. Currently, he works in the Manufacturing Engineering and Production Technology Department of the Modern Academy for Engineering and Technology, Cairo, Egypt. Previously, he was a professor at the Military Technical College, Cairo, Egypt. He is the author or co-author of 55 papers published in international journals and presented at refereed conferences, and the supervisor of 24 M.Sc. and Ph.D. theses.

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E-mail: info@mathworks.com
Web: www.mathworks.com

Contents

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Preface

This book examines the construction, principles of operation, and calculation of hydraulic power systems. Special attention is paid to building a solid theoretical background in the subject, which should enable the reader to go on to further study and analysis of the static and dynamic performance of the different fluid power elements and systems. In addition to theory, the book includes case studies of typical construction elements of hydraulic power systems. These elements are categorized, and the special features of their design and performance are discussed.

Following are the chapters in this book:

Chapter 1, Introduction to Hydraulic Power Systems
Chapter 2, Hydraulic Oils and Theoretical Background
Chapter 3, Hydraulic Transmission Lines
Chapter 4, Hydraulic Pumps
Chapter 5, Hydraulic Control Valves
Chapter 6, Accessories
Chapter 7, Hydraulic Actuators
Chapter 8, Hydraulic Servo Actuators
Chapter 9, Electrohydraulic Servovalve Technology
Chapter 10, Modeling and Simulation of Electrohydraulic Servosystems
Chapter 11, Introduction to Pneumatic Systems

I am indebted to my colleagues Prof. Dr. Ibrahim Saleh and Prof. Dr. Saad Kassem for the continuous, fruitful, and stimulating discussions we had, and for their objective comments on the book as a whole.

I would also like to express my gratitude to Bosch Rexroth AG, Norgren Ltd., Moog Inc., Famic Technologies Inc., and Olaer Group Ltd. for their kind support and permission to use their illustrations in this book.

Finally, I would like to extend my appreciation and gratitude to the staff of McGraw-Hill Professional, especially Taisuke Soda, senior editor; Stephen M. Smith, editing manager; Pamela A. Pelton, senior production supervisor; and Jeff Weeks, senior art director. I would also like to thank Arushi Chawla, project manager, and her team at International Typesetting and Composition; Michael McGee for copy editing; Broccoli Information Management for creating the index; Constance Blazewicz for proofreading; and RR Donnelley for printing and binding.

M. Galal Rabie, Ph.D.

Fluid Power Engineering

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CHAPTER 1

Introduction to Hydraulic Power Systems

1.1 Introduction

God created the first and most wonderful hydraulic system. It includes a double pump delivering a fluid flow rate of about 10 L/min at 0.16 bar maximum pressure. This pump feeds a piping network stretching more than 100,000 km. That's nearly two and a half times around the Earth. It operates continuously for a very long time, mostly maintenance free. It is the human blood circulatory system. By the age of 50 years, the hearts of 10 men should have pumped a volume of blood equaling that of the great Egyptian pyramid (2,600,000 m^3).

As for the hydraulic power systems developed by man, their history started practically 350 years ago. In 1647, Blaise Pascal published the fundamental law of hydrostatics: "Pressure in a fluid at rest is transmitted in all directions." In 1738, Bernoulli published his book *Hydrodynamica*, which included his kinetic-molecular theory of gases, the principle of jet propulsion, and the law of the conservation of energy. By the middle of the nineteenth century, fluid power started playing an important role in both the industrial and civil fields. In England, for example, many cities had central industrial hydraulic distribution networks, supplied by pumps driven by steam engines.

Before the universal adoption of electricity, hydraulic power was a sizable competitor to other energy sources in London. The London Hydraulic Power Company generated hydraulic power for everything from dock cranes and bridges to lifts in private households in Kensington and Mayfair. In the 1930s, during the glory days of hydraulic power, a 12 m^3/min average flow rate of water was pumped beneath the streets of London, raising and lowering almost anything that needed to be moved up and down. As a power source, hydraulic power was cheap, efficient, and easily transmitted through 300 km of underground cast-iron piping.

However, as electricity became cheaper and electronically powered equipment grew increasingly sophisticated, so industry and private citizens began to abandon hydraulic power.

High-pressure fluid power systems were put into practical application in 1925, when Harry Vickers developed the balanced vane pump. Today, fluid power systems dominate most of the engineering fields, partially or totally.

1.2 The Classification of Power Systems

Power systems are used to transmit and control power. This function is illustrated by Fig. 1.1. The following are the basic parts of a power system.

1. Source of energy, delivering mechanical power of rotary motion. Electric motors and internal combustion engines (ICE) are the most commonly used power sources. For special applications, steam turbines, gas turbines, or hydraulic turbines are used.
2. Energy transmission, transformation, and control elements.
3. Load requiring mechanical power of either rotary or linear motion.

In engineering applications, there exist different types of power systems: mechanical, electrical, and fluid. Figure 1.2 shows the classification of power systems.

1.2.1 Mechanical Power Systems

The mechanical power systems use mechanical elements to transmit and control the mechanical power. The drive train of a small car is a typical example of a mechanical power system (see Fig. 1.3). The gearbox (3) is connected to the engine (1) through the clutch (2). The input

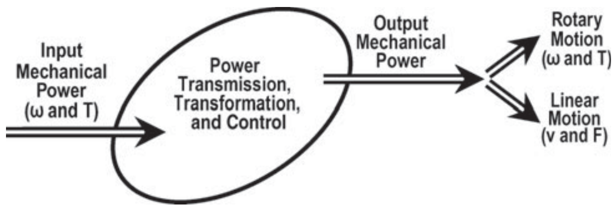


FIGURE 1.1 The function of a power system.

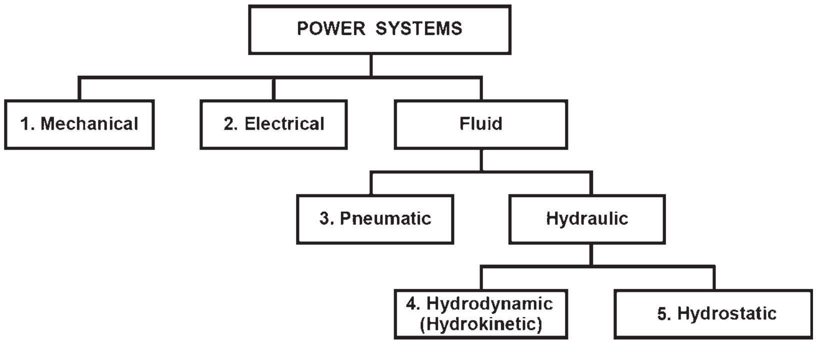


FIGURE 1.2 The classification of power systems.

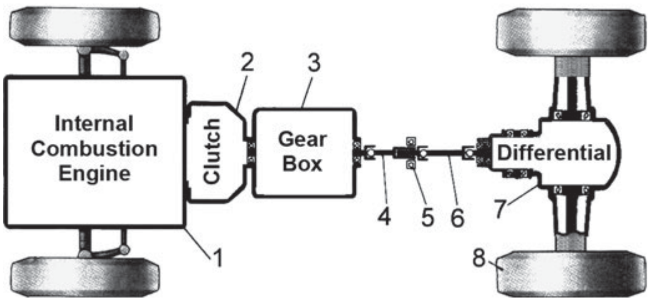


FIGURE 1.3 An automotive drive train.

shaft of the gear box turns at the same speed as the engine. Its output shaft (4) turns at different speeds, depending on the selected gear transmission ratio. The power is then transmitted to the wheels (8) through the universal joints (5), drive shaft (6), and differential (7).

When compared with other power systems, mechanical power systems have advantages such as relatively simple construction, maintenance, and operation, as well as low cost. However, their power-to-weight ratio is minimal, the power transmission distance is too limited, and the flexibility and controllability are poor.

1.2.2 Electrical Power Systems

Electrical power systems solve the problems of power transmission distance and flexibility, and improve controllability. Figure 1.4 illustrates the principal of operation of electrical power systems. These systems offer advantages such as high flexibility and a very long power transmission distance, but they produce mainly rotary motion. Rectilinear motion, of high power, can be obtained by converting the rotary motion into rectilinear motion by using a suitable gear system

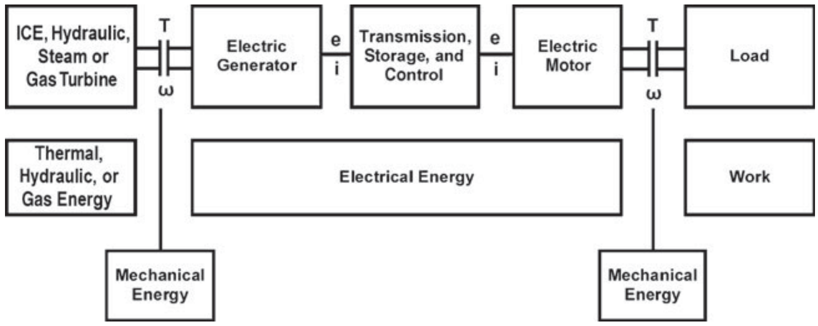


Figure 1.4 Power transmission in an electrical power system.

or by using a drum and wire. However, holding the load position requires a special braking system.

1.2.3 Pneumatic Power Systems

Pneumatic systems are power systems using compressed air as a working medium for the power transmission. Their principle of operation is similar to that of electric power systems. The air compressor converts the mechanical energy of the prime mover into mainly pressure energy of compressed air. This transformation facilitates the transmission and control of power. An air preparation process is needed to prepare the compressed air for use. The air preparation includes filtration, drying, and the adding of lubricating oil mist. The compressed air is stored in the compressed air reservoirs and transmitted through rigid and/or flexible lines. The pneumatic power is controlled by means of a set of pressure, flow, and directional control valves. Then, it is converted to the required mechanical power by means of pneumatic cylinders and motors (expanders). Figure 1.5 illustrates the process of power transmission in pneumatic systems.

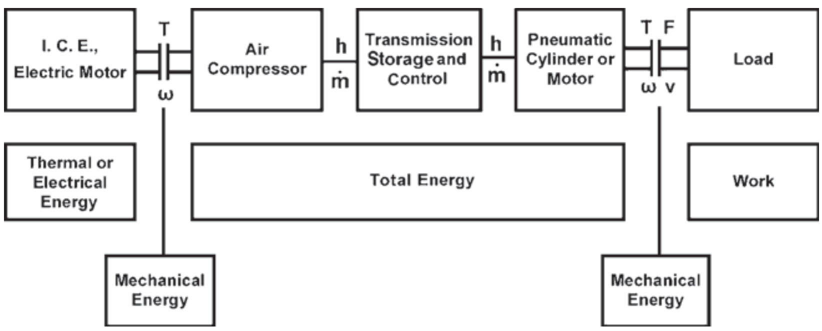


Figure 1.5 Power transmission in a pneumatic power system.

1.2.4 Hydrodynamic Power Systems

The hydraulic power systems transmit mechanical power by increasing the energy of hydraulic liquids. Two types of hydraulic power systems are used: hydrodynamic and hydrostatic.

Hydrodynamic (also called hydrokinetic) power systems transmit power by increasing mainly the kinetic energy of liquid. Generally, these systems include a rotodynamic pump, a turbine, and additional control elements. The applications of hydrodynamic power systems are limited to rotary motion. These systems replace the classical mechanical transmission in the power stations and vehicles due to their high power-to-weight ratio and better controllability.

There are two main types of hydrodynamic power systems: hydraulic coupling and torque converter.

A hydraulic coupling (see Fig. 1.6) is essentially a fluid-based clutch. It consists of a pump (2), driven by the input shaft (1), and a turbine (3), coupled to the output shaft (4). When the pump impeller rotates, the oil flows to the turbine at high speed. The oil then impacts the turbine blades, where it loses most of the kinetic energy it gained from the pump. The oil re-circulates in a closed path inside the coupling and the power is transmitted from the input shaft to the output shaft. The input torque is practically equal to the output torque.

The torque converter is a hydraulic coupling with one extra component: the stator, also called the reactor (5). (See Fig. 1.7.) The stator consists of a series of guide blades attached to the housing. The torque

FIGURE 1.6 Hydraulic coupling.

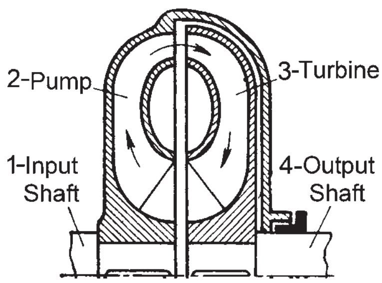
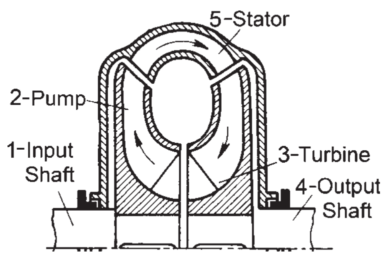


FIGURE 1.7 Torque converter.



converters are used where it is necessary to control the output torque and develop a transmission ratio, other than unity, keeping acceptable transmission efficiency.

1.2.5 Hydrostatic Power Systems

In the hydrostatic power systems, the power is transmitted by increasing mainly the pressure energy of liquid. These systems are widely used in industry, mobile equipment, aircrafts, ship control, and others. This text deals with the hydrostatic power systems, which are commonly called *hydraulic power systems*. Figure 1.8 shows the operation principle of such systems.

The concepts of hydraulic energy, power, and power transformation are simply explained in the following: Consider a forklift that lifts a load vertically for a distance y during a time period Δt (see Fig. 1.9). To fulfill this function, the forklift acts on the load by a vertical force F. If the friction is negligible, then in the steady state,

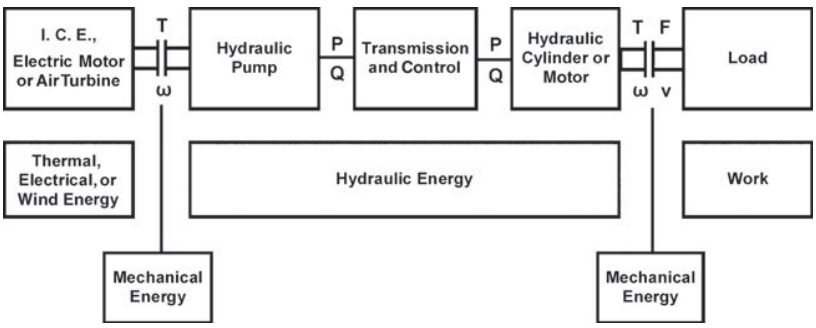


FIGURE 1.8 Power transmission in a hydraulic power system.

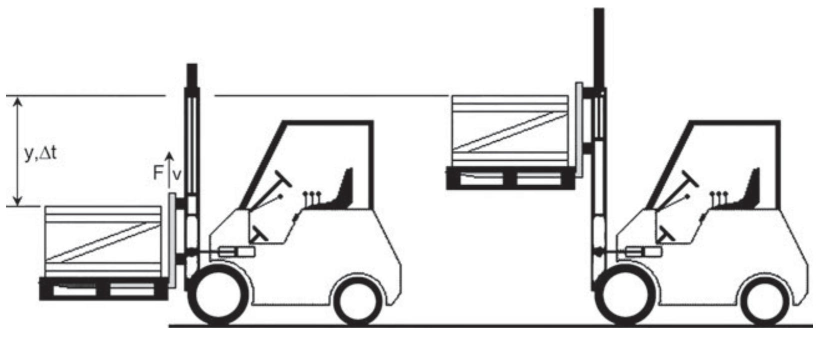


FIGURE 1.9 Load lifting by a forklift.

this force equals the total weight of the displaced parts ($F = mg$). The work done by the forklift is

$$W = Fy \tag{1.1}$$

By the end of the time period, Δt, the potential energy of the lifted body is increased by E, where

$$E = mgy = Fy \tag{1.2}$$

where E = Gained potential energy, J
F = Vertically applied force, N
g = Coefficient of gravitational force, m/s^2
m = Mass of lifted body, kg
W = Work, J
y = Vertical displacement, m

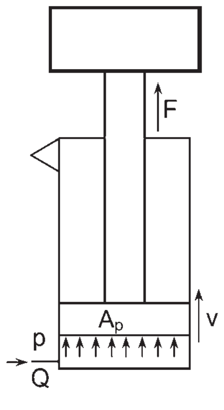
This amount of energy (E) is gained during time period Δt. The energy delivered to the lifted body per unit of time is the delivered power N, where

$$N = Fy/\Delta t = Fv \tag{1.3}$$

where N = Mechanical power delivered to the load, W
v = Lifting speed, m/s

The load is lifted by a hydraulic cylinder. This cylinder acts on the lifted body by a force F and drives it with a speed v. Figure 1.10 illustrates the action of the hydraulic cylinder. It is a single acting cylinder which extends by the pressure force and retracts by the body weight. The pressurized oil flows to the hydraulic cylinder at a flow rate Q (volumetric flow rate, m^3/s) and its pressure is p. Neglecting the friction in the cylinder, the pressure force which drives the piston in the extension direction is given by $F = pA_p$.

Figure 1.10 Lifting a body vertically by a hydraulic cylinder.



During the time period, Δt, the piston travels vertically a distance y. The volume of oil that entered the cylinder during this period is $V = A_p y$.
Then, the oil flow rate that entered the cylinder is

$$Q = \frac{V}{\Delta t} = \frac{A_p y}{\Delta t} = A_p v \tag{1.4}$$

Assuming an ideal cylinder, then the hydraulic power inlet to the cylinder is

$$N = Fv = pA_p Q/A_p = Qp \tag{1.5}$$

where A_p = Piston area, m^2
p = Pressure of inlet oil, Pa
Q = Flow rate, m^3/s
V = Piston swept volume, m^3

The mechanical power delivered to the load equals the hydraulic power delivered to the cylinder. This equality is due to the assumption of zero internal leakage and zero friction forces in the cylinder. The assumption of zero internal leakage is practical, for normal conditions. However, for aged seals, there may be non-negligible internal leakage. A part of the inlet flow leaks and the speed v becomes less than (Q/A_p). Also, a part of the pressure force overcomes the friction forces. Thus, the mechanical power output from the hydraulic cylinder is actually less than the input hydraulic power ($Fv < Qp$).

1.3 Basic Hydraulic Power Systems

Figure 1.11 shows the circuit of a simple hydraulic system, drawn in both functional-sectional schemes and standard hydraulic symbols. The function of this system is summarized in the following:

1. The prime mover supplies the system with the required mechanical power. The pump converts the input mechanical power to hydraulic power.
2. The energy-carrying liquid is transmitted through the hydraulic transmission lines: pipes and hoses. The hydraulic power is controlled by means of valves of different types. This circuit includes three different types of valves: a pressure control valve, a directional control valve, and a flow control (throttle-check) valve.
3. The controlled hydraulic power is communicated to the hydraulic cylinder, which converts it to the required mechanical power. Generally, the hydraulic power systems provide both rotary and linear motions.

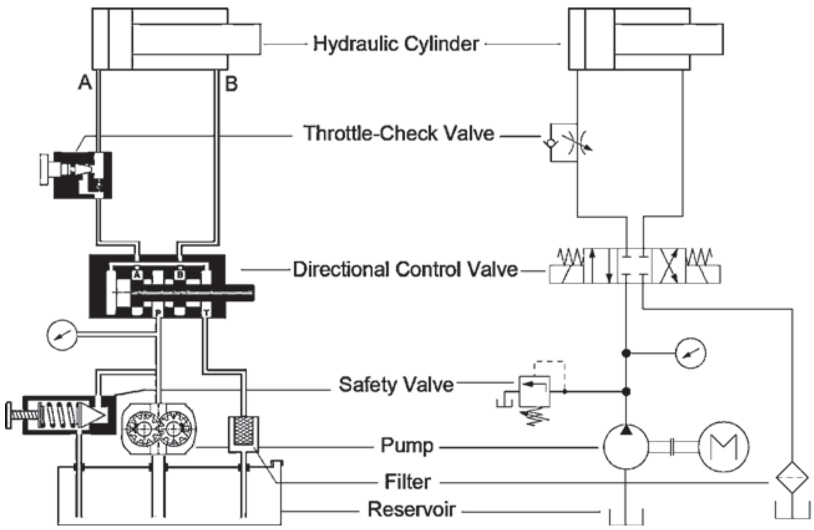


Figure 1.11 Hydraulic system circuit, schematic, and symbolic drawings.

1.4 The Advantages and Disadvantages of Hydraulic Systems

The main advantages of the hydraulic power systems are the following:

1. High power-to-weight ratio.
2. Self-lubrication.
3. There is no saturation phenomenon in the hydraulic systems compared with saturation in electric machines. The maximum torque of an electric motor is proportional to the electric current, but it is limited by the magnetic saturation.
4. High force-to-mass and torque-to-inertia ratios, which result in high acceleration capability and a rapid response of the hydraulic motors.
5. High stiffness of the hydraulic cylinders, which allows stopping loads at any intermediate position.
6. Simple protection against overloading.
7. Possibility of energy storage in hydraulic accumulators.
8. Flexibility of transmission compared with mechanical systems.
9. Availability of both rotary and rectilinear motions.
10. Safe regarding explosion hazards.

Hydraulic power systems have the following disadvantages:

1. Hydraulic power is not readily available, unlike electrical. Hydraulic generators are therefore required.

2. High cost of production due to the requirements of small clearances and high precision production process.
3. High inertia of transmission lines, which increases their response time.
4. Limitation of the maximum and minimum operating temperature.
5. Fire hazard when using mineral oils.
6. Oil filtration problems.

1.5 Comparing Power Systems

Table 1.1 shows a brief comparison of the different power systems, while Table 1.2 gives the power variables in mechanical, electrical, and hydraulic systems.

System Property	Mechanical	Electrical	Pneumatic	Hydraulic
Input energy source	ICE and electric motor	ICE and hydraulic, air or steam turbines	ICE, electric motor, and pressure tank	ICE, electric motor, and air turbine
Energy transfer element	Mechanical parts, levers, shafts, gears	Electrical cables and magnetic field	Pipes and hoses	Pipes and hoses
Energy carrier	Rigid and elastic objects	Flow of electrons	Air	Hydraulic liquids
Power-to-weight ratio	Poor	Fair	Best	Best
Torque/inertia	Poor	Fair	Good	Best
Stiffness	Good	Poor	Fair	Best
Response speed	Fair	Best	Fair	Good
Dirt sensitivity	Best	Best	Fair	Fair
Relative cost	Best	Best	Good	Fair
Control	Fair	Best	Good	Good
Motion type	Mainly rotary	Mainly rotary	Linear or rotary	Linear or rotary

Table 1.1 Comparison of Power Systems

	Effort		Flow		Power	
	Variable	**Units**	**Variable**	**Units**	**Variable**	**Units**
Mech. Linear	Force, F	N	Velocity, v	m/s	$N = Fv$	W
Mech. Rotary	Torque, T	Nm	Angular speed, ω	rad/s	$N = \omega T$	W
Electrical (DC)	Electric potential, e	V	Electric current, i	A	$N = ei$	W
Hydraulic	Pressure, P	Pa	Flow rate, Q	m^3/s	$N = PQ$	W

TABLE 1.2 Effort, Flow, and Power Variables of Different Power Systems

1.6 Exercises

1. State the function of the power systems.

2. Discuss briefly the principle of operation of the different power systems giving the necessary schemes.

3. Draw the circuit of a simple hydraulic system, in standard symbols, and explain briefly the function of its basic elements.

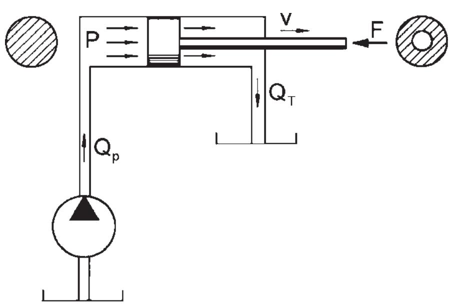
4. State the advantages and disadvantages of hydraulic power systems.

5. Draw the circuit of a simple hydraulic system, including a pump, directional control valves, hydraulic cylinder, relief valve, and pressure gauge. State the function of the individual elements and discuss in detail the power transmission and transformation in the hydraulic power systems.

6. The given figure shows the extension mode of a hydraulic cylinder. Neglecting the losses in the transmission lines and control valves, calculate the loading force, F, returned flow rate, Q_T, piston speed, v, cylinder output mechanical power, N_m, and pump output hydraulic power, N_h. Comment on the calculation results, given

Delivery line pressure $P = 200$ bar

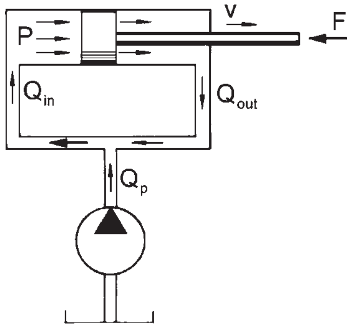
Pump flow rate $Q_p = 40$ L/min



Piston diameter $D = 100$ mm

Piston rod diameter $d = 70$ mm

7. The given figure shows the extension mode of a hydraulic cylinder, in differential connection. The losses in the transmission lines and control valves were neglected. Calculate the loading force, F, inlet flow rate, Q_{in}, returned flow rate, Q_{out}, piston speed, v, cylinder output mechanical power, N_m, and pump output hydraulic power, N_h. Comment on the calculation results compared with the case of problem 6, given



Delivery line pressure $P = 200$ bar

Pump flow rate $Q_P = 40$ L/min

Piston diameter $D = 100$ mm

Piston rod diameter $d = 70$ mm

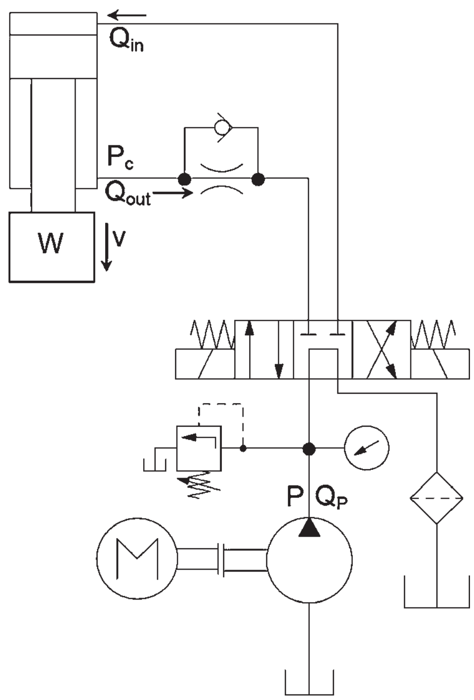
8. Shown is the hydraulic circuit of a load-lifting hydraulic system. The lowering speed is controlled by means of a throttle-check valve. Discuss the construction and operation of this system. Redraw the hydraulic circuit in the load-lowering mode, then calculate the pressure in the cylinder rod side, P_C, the inlet flow rate, Q_{in}, outlet flow rate, Q_{out}, pump flow rate, Q_P, pump output power, N_h, and the area of the throttle valve, A_t. Neglect the hydraulic losses in the system elements, except the throttle valve.

The flow rate through the throttling element is given by: $Q = C_d A_t \sqrt{2\Delta P/\rho}$, where

Q = Flow rate, m^3/s	C_d = Discharge coefficient
A_t = Throttle area, m^2	ΔP = Pressure difference, Pa
ρ = Oil density, kg/m^3	

Given

Pump exit pressure = 30 bar	Piston speed = 0.07 m/s
Piston area $A_P = 78.5$ cm^2	Piston rod side area $A_r = 40$ cm^2
Oil density = 870 kg/m^3	Discharge coefficient = 0.611
Safety valve is pre-set at 350 bar	Weight of the body = 30 kN



9. Redraw the circuit of problem 8 in lifting mode. For the same pump flow rate, safety valve setting, and dimensions, calculate the maximum load that the system can lift. Calculate all of the system operating parameters at this mode. Neglect the hydraulic losses in the system elements, except for the throttle valve.

1.7 Nomenclature

A_p = Piston area, m^2
E = Gained potential energy, J
F = Vertically applied force, N
g = Coefficient of gravitational force, m/s^2
m = Mass of lifted body, kg
N = Mechanical power delivered to the load, W
p = Pressure, Pa
Q = Flow rate, m^3/s
v = Lifting speed, m/s
V = Piston swept volume, m^3
W = Work, J
y = Vertical displacement, m

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Laboratory Book

Hydraulic Power Systems

Laboratory Work

Experiment No. 1
Centrifugal Pump Characteristics

Students Name:..
Class:...........................   Nr.:.............................
Date:.................................

Centrifugal Pump Characteristics

This experiment is designed to measure the flow characteristics of a centrifugal pump; Head (Flow rate). The set-up includes:

- the control of the pump exit pressure
- the measurement of the pump exit pressure
- the calculation of pressure head and
- the measurement of the pump flow rate.

1. Test stand

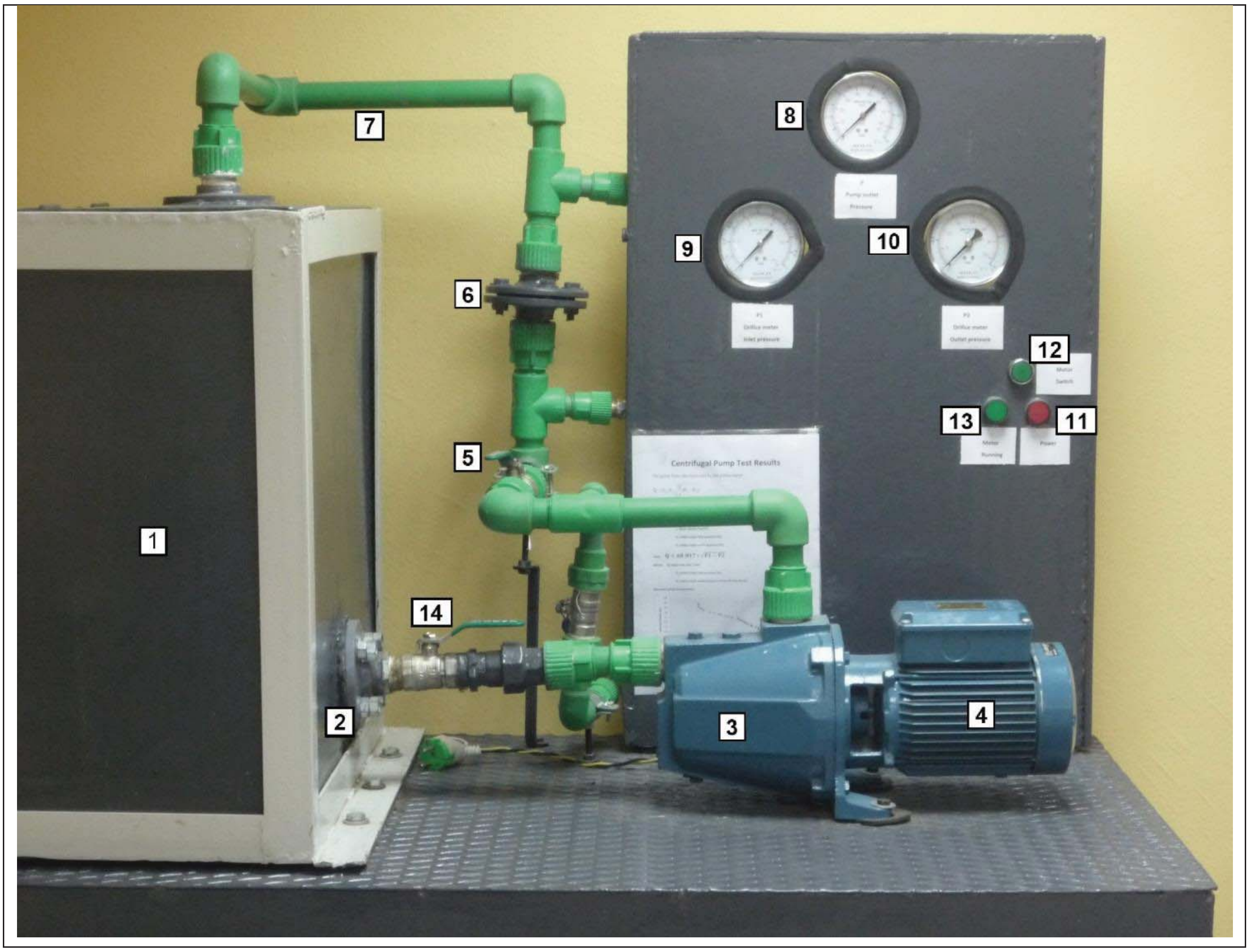


Fig.1 Centrifugal pump test stand

The test stand is shown by Fig.1, while its hydraulic circuit is given by Fig.2. The system consists of the following elements:

(1) Water tank	(2) Pump suction pipe
(3) Centrifugal pump	(4) Electric motor (n=2800 rpm)
(5) Throttle valve	(6) Orifice flow meter
(7) Return pipe line	(8) pump exit pressure gauge
(9) Orifice meter inlet pressure gauge	(10) Orifice meter outlet pressure gauge
(11) Power indicating lamb	(12) Motor on/off switch
(13) Motor running indicating lamb	(14) Pump suction valve

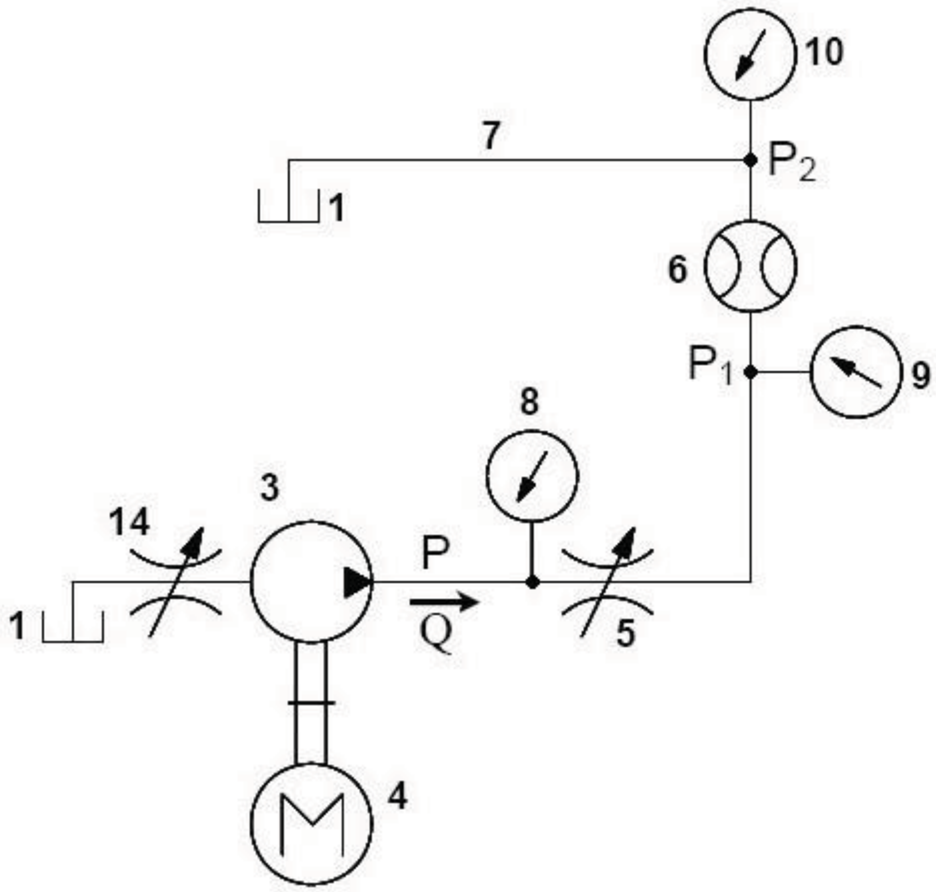


Fig.2 Hydraulic circuit of the centrifugal pump test stand

The pump exit pressure (P) is measured in (bar). The corresponding head is:

$$H = P/\rho g$$

For water $\boxed{H = 10\ P}$ (Where P is in bar and H is in meters)

The pump exit pressure is controlled by the throttle valve (5) and measured by the pressure gauge (8).

The pump flow rate is measured by the orifice flow meter (6) and pressure gauges (9&10). The flow rate through the orifice meter is calculated as follows.

$$Q = C_d A_o \sqrt{\frac{2}{\rho}(P_1 - P_2)}$$

Where Q = Water flow rate, m^3/s

A_o = Orifice area = 78.54 mm^2

ρ = Water Density = 1000 kg/m^3

P_1 = Orifice meter inlet pressure, Pa

P_2 = Orifice meter outlet Pressure, Pa

C_d = Discharge coefficient, (= 0.611 for sharp edged orifice)

Or $$\boxed{Q = 68.817\sqrt{P_1}}$$

Where Q = Water flow rate, L/min

P_1 = Orifice meter inlet pressure, bar

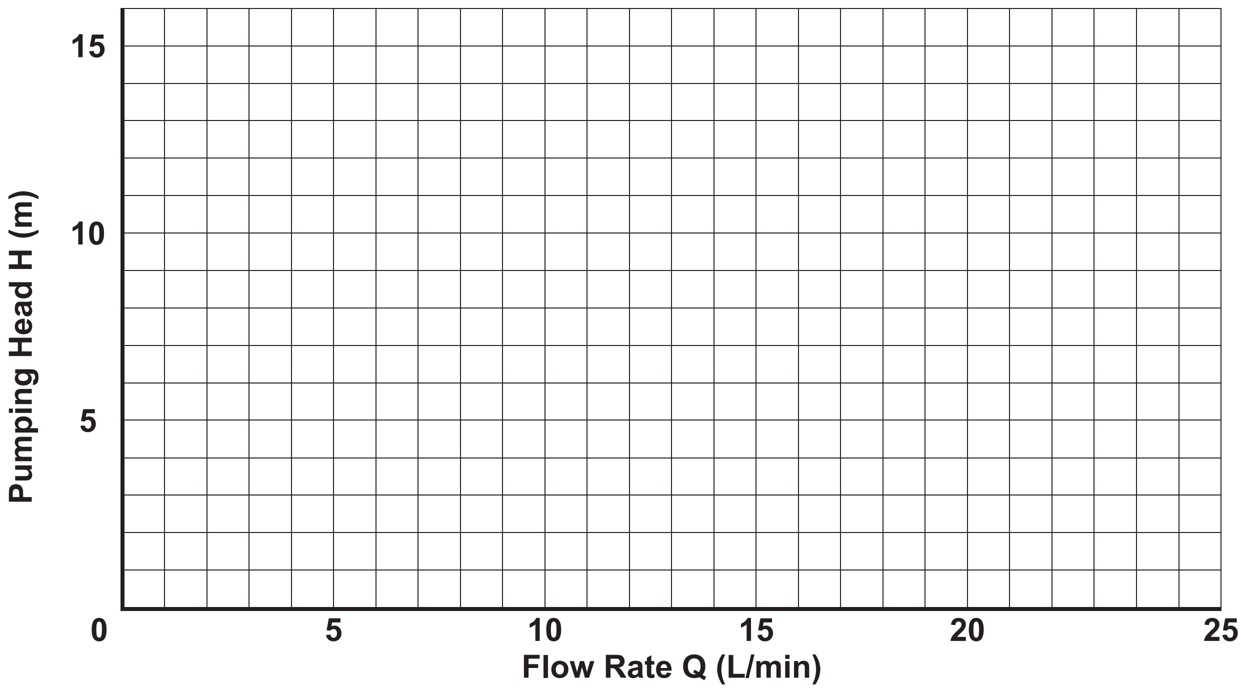
P_2 = Orifice meter outlet Pressure (= 0 bar for this setup)

2. Steps of measurements

(1) Close the throttle valve (5) completely.
(2) Connect the power cable; the power lamb (13) goes on (red color).
(3) Switch the electric motor on, switch No. (12); the indicating lamb (11) goes on (green color)
(4) Get the readings of the three pressure gauges, and record them on the given table.
(5) Open the throttle valve (5) gradually and record the pressure gauges readings until the valve is fully open.
(6) Close the throttle valve (5) gradually and record the pressure gauges readings until the valve is fully closed.
(7) Switch the electric motor off, switch No. (12); the indicating lamb (11) goes off.
(8) Disconnect the power cable; the power lamb (13) goes off.

3. Results

No.	P	P_1	P_2	Q	H
	bar	bar	bar	$Q = 68.817\sqrt{P_1}$ L/min	$H = 10\ P$ m
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					



4. Discussion and conclusion

Hydraulic Power Systems

Laboratory Work

Experiment No. 2

Hydraulic Training Unit

Students Name:...

Class:............................ Nr.:..............................

Date:..................................

1. **Aims:**

a. Recognize the construction of the hydraulic training unit.
b. Understand the function of its hydraulic circuit.
c. To be acquainted with the existing hydraulic elements, their function and symbol.
d. Put the power pack in operation and adjust its relief pressure.

2. HYDRAULIC CIRCUIT OF THE POWER PACK

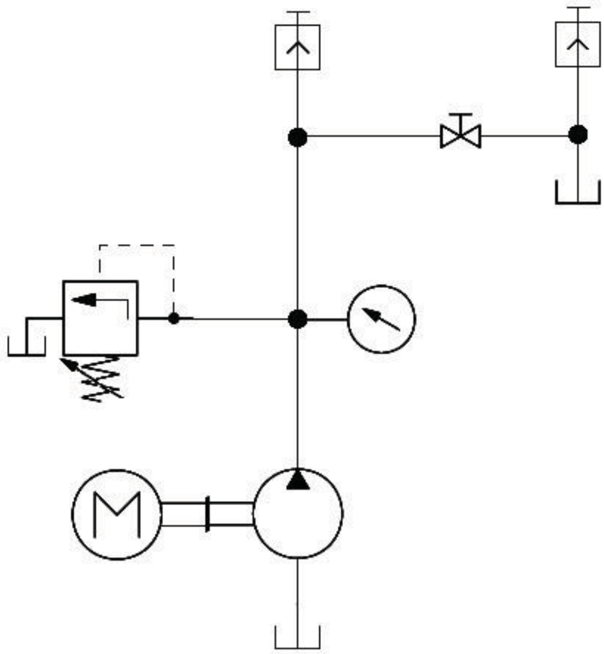


Fig.2.1 Hydraulic circuit of the power pack

Add the elements number, as listed in table 2.1, then explain briefly the function of the circuit.

3. ELEMENTS OF THE HYDRAULIC TRAINING UNIT

Table 2.1 gives the numbering and names of the basic elements of the hydraulic training unit. Connect the numbers to the corresponding element on all of the images.

Fig.2.2 Front view of the hydraulic training unit

Fig.2.3 Front view of the power pack

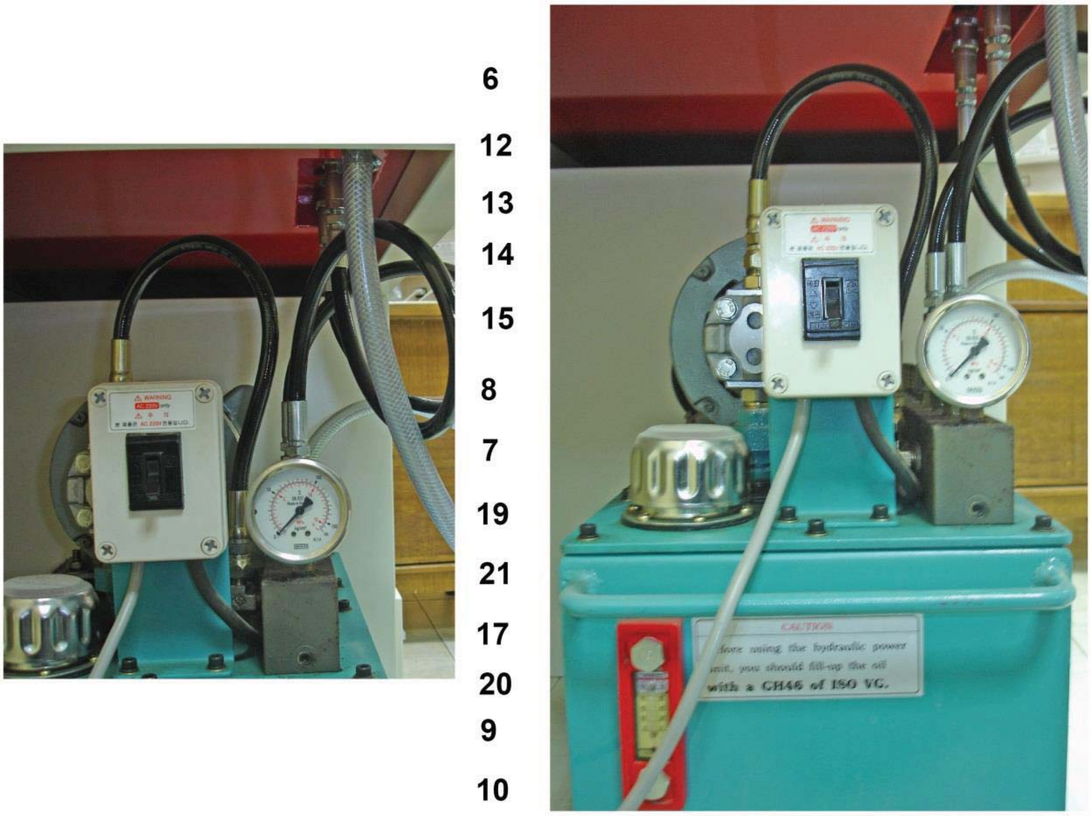


Fig.2.4 Side view of the power pack

By-Pass opened

By-pass closed

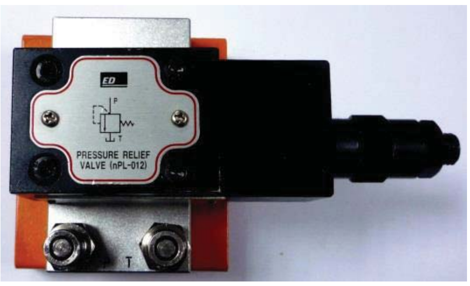
Fig.2.5 By-pass arrangement

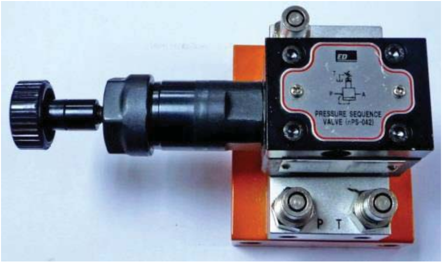
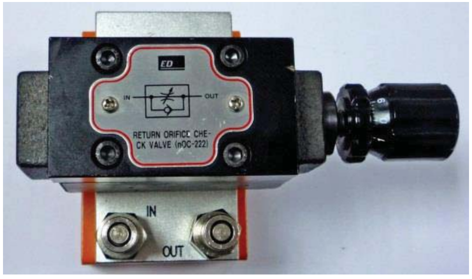
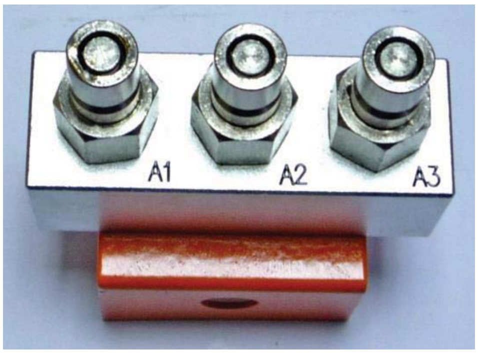
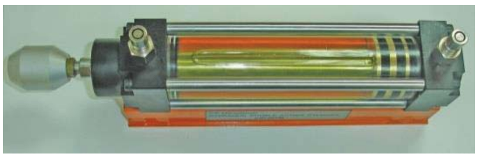
Table 2.1 Elements of the hydraulic training unit

No.	Name
1	Metallic panel for attachment of hydraulic elements
2	Electric control panel
3	Hydraulic pressure line connector
4	Return line connector
5	By-pass valve
6	Oil sump
7	Gear pump
8	Electric motor
9	Hydraulic tank
10	Oil level indicator
11	Pump suction line
12	Pump delivery line
13	High pressure line
14	Return line
15	Oil sump drain line
16	Drain manifold
17	Control block
18	Safety valve
19	Pressure gauge
20	Air breather
21	Main switch

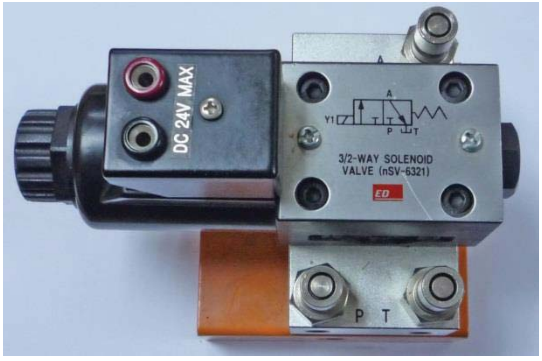
4. AVAILABLE VALVES AND ELEMENTS

In addition to the flexible hoses, the following elements are available. State briefly the function of each of them.

Element	Symbol and Function
Check valve   	
Pilot operated check valve  	
Relief valve  	

Sequence valve 	
Throttle-check valve 	
Connectors 	
Cylinder 	
Transparent cylinder 	

Limit switch 	
Pressure gauge 	
Pressure Switch 	

2/2 DCV  	
3/2 DCV  	
4/2 DCV  	
4/3 Directional control valve  	

4. REGULATIONS OF POWER PACK OPERATION

Before operation:

Operation and relief valve setting:

Comments:

Hydraulic Power Systems

Laboratory Work

Experiment No. 3

Cavitation in Hydraulic Displacement pumps

Students Name:..

Class:............................ Nr.:..............................

Date:..................................

1. AIMS

1- Understand the cavitation phenomenon
2- Define and understand the displacement pump flow characteristics
3- Visualize the cavitation phenomenon
4- Measure the pump flow characteristics

2. HYDRAULIC SYSTEM OF THE PUMP TEST STAND

2.1 Construction of the hydraulic system

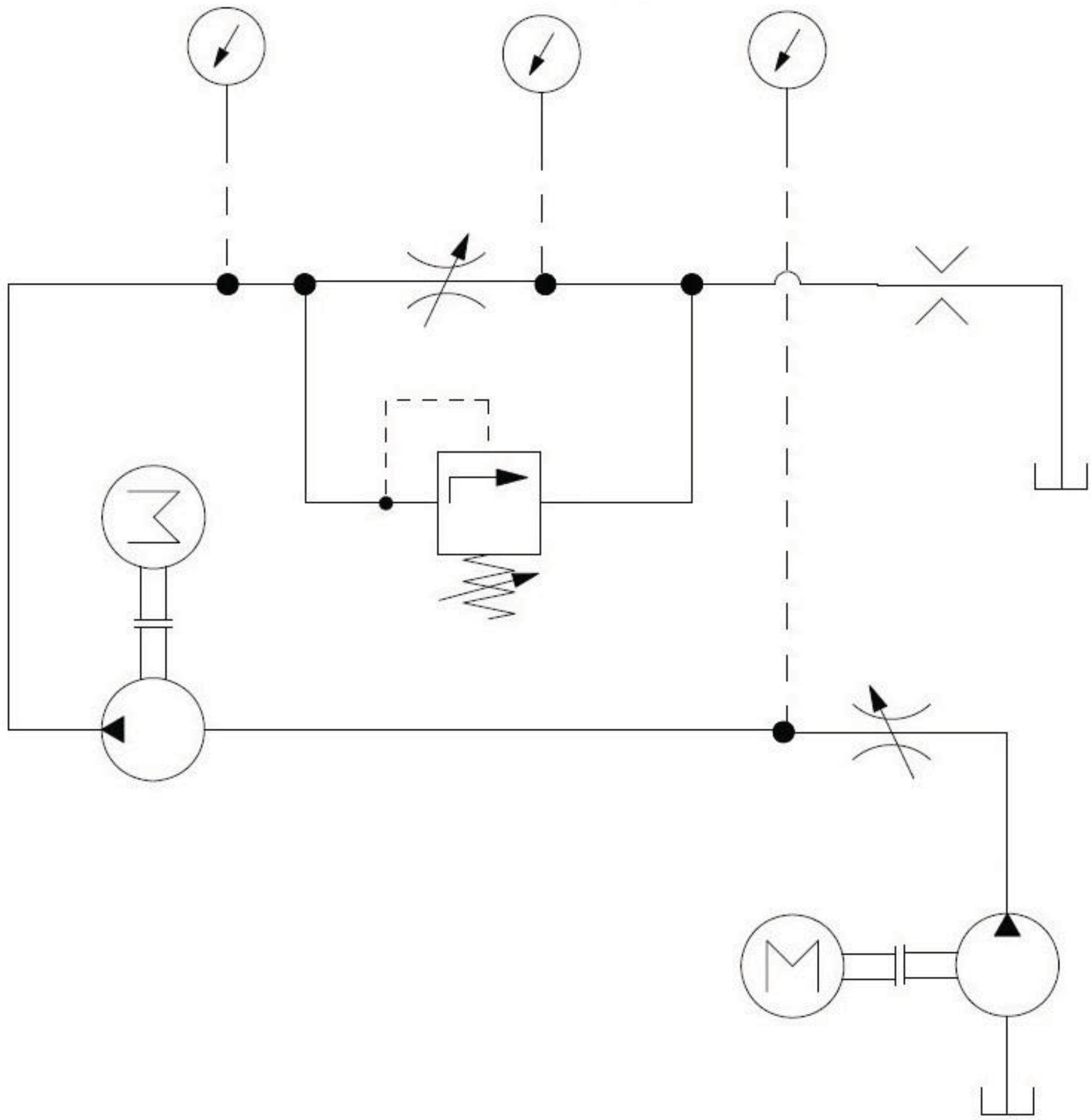


Fig.3.1 Hydraulic circuit of the pump test stand

Add the elements number, as listed in table 2.1, to Fig.3.1, and then explain briefly the construction of system.

Table 3.1 Elements of the pump test stand

No	Part Name
1	Hydraulic Tank(Reservoir)
2	Filling neck with air breather
3	Oil level indicator
4	Booster pump suction line
5	Booster pump
6	Booster pump driving motor
7	Booster pump exit line
8	Throttle valve
9	Hose connecting suction pressure to pressure gauge
10	Transparent pipe
11	Gear pump suction line
12	Gear Pump
13	Gear pump driving motor
14	Gear pump exit line
15	Relief valve
16	Throttle valve
17	Orifice flow meter
18	Pressure gauge (Gear Pump exit pressure)
19	Pressure gauge (Orifice meter inlet pressure)
20	Pressure gauge (Gear Pump inlet pressure)
21	Booster pump electric switch
22	Booster pump operation indicating lamp
23	Gear pump electric switch
24	Gear pump operation indicating lamp

Fig.3.2 Pump test stand

1
2
3
4
5
6
7

Fig.3.3

1
2
3
4
5
6
7

Fig.3.4

8
9
10

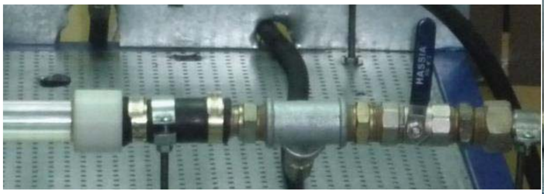


Fig.3.5

24
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22
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10

Fig.3.6

11
12
13
14

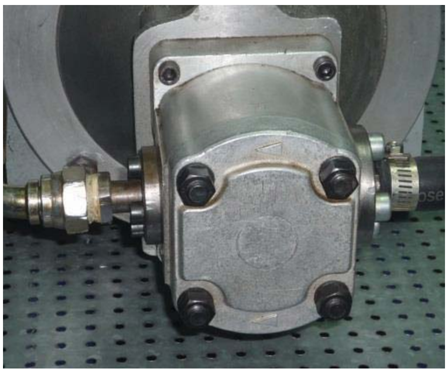

Fig.3.7

12
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14

Fig.3.8

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17
16
15
14

17
18

Fig.3.9

Fig.3.10

23
14
15
16

21
22
23
24
19
20

Fig.3.11

Fig.3.12

2.2 Operation of the hydraulic system

2.2.1 Gear Pump Inlet Pressure Control

2.2.2 Gear Pump Exit Pressure Control

2.2.3 Gear Pump Flow Rate Measurement

3. MEASUREMENT OF THE PUMP CHARACTERISTICS

Flow Characteristics; $Q_P(P_P)$ at constant inlet pressure

Inlet Pressure = Constant = bar

P_P (bar)	P_{FM} (bar)	Q_P (Lit/min)

P_P (bar)	P_{FM} (bar)	Q_P (Lit/min)

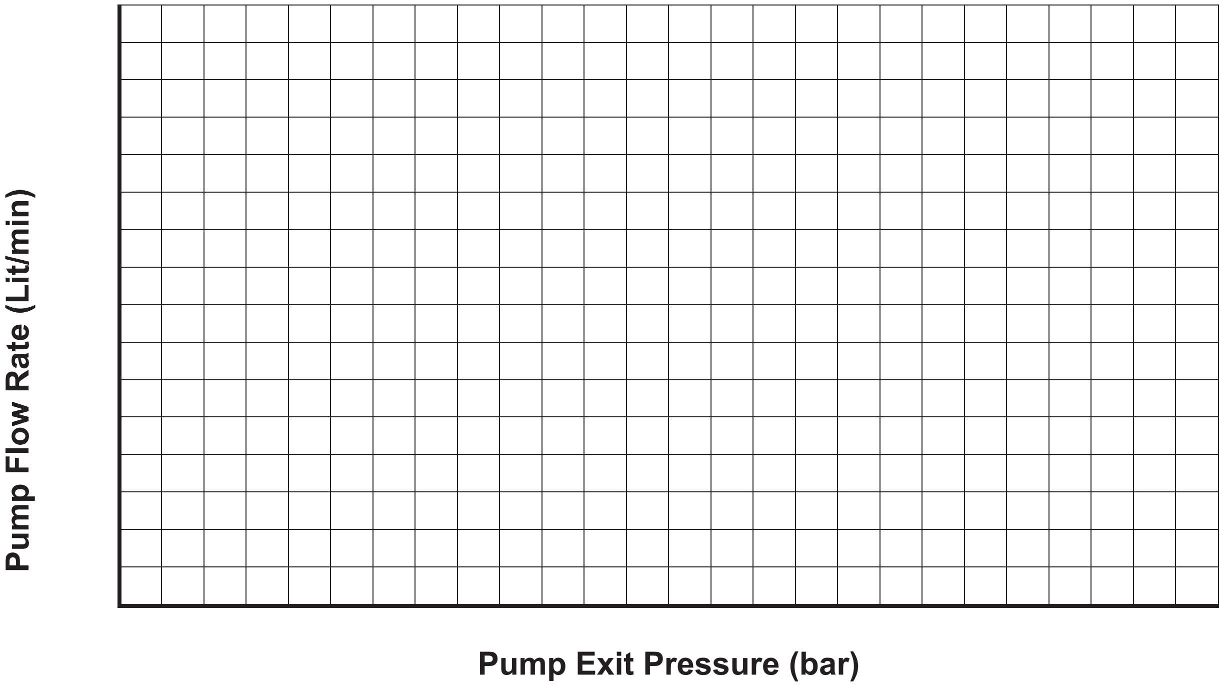


Fig.3. Pump Flow Characteristics

Comments on the Pump Flow Characteristics

Hydraulic Power Syst

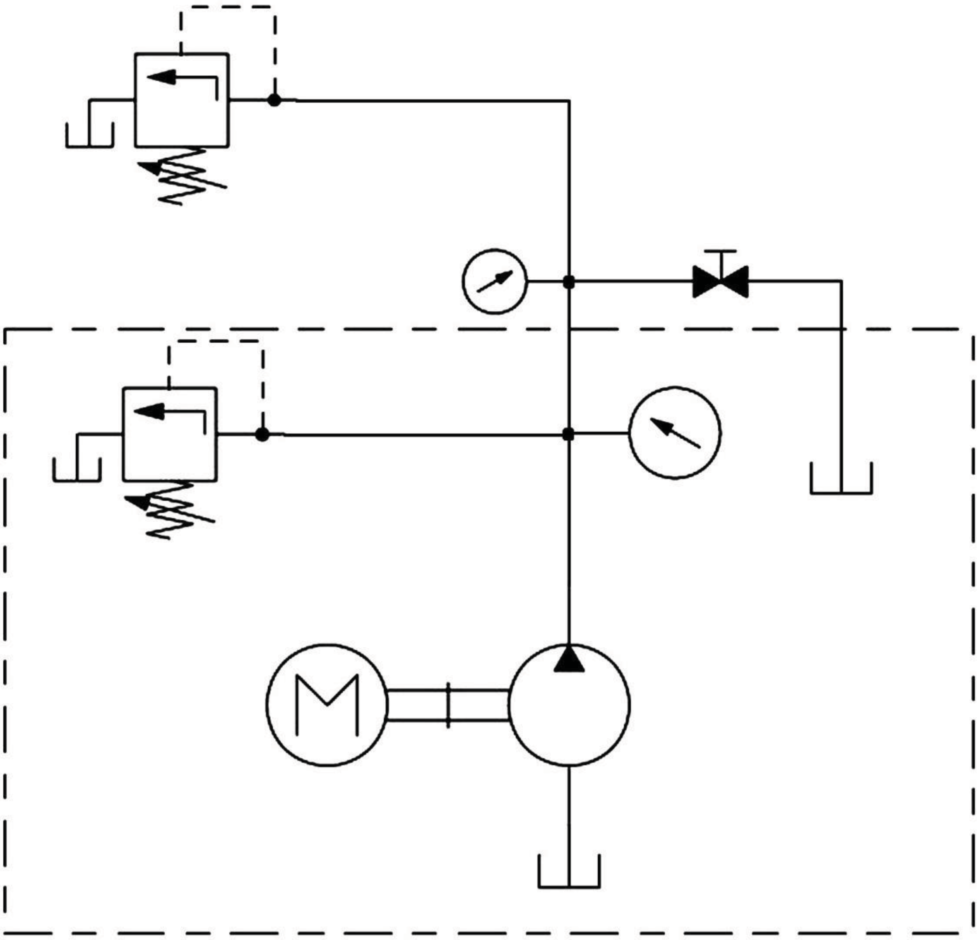
Laboratory Work

Hydraulic Circuits

Students Name:...

Class:............................ Nr.:..............................

Date:..................................



Hydraulic circuit No.1

Hydraulic Circuit No.1

1. Number the elements of the circuit and state the names and function of the circuit parts in the following table

No.	Name	Function
1		
2		
3		
4		
5		
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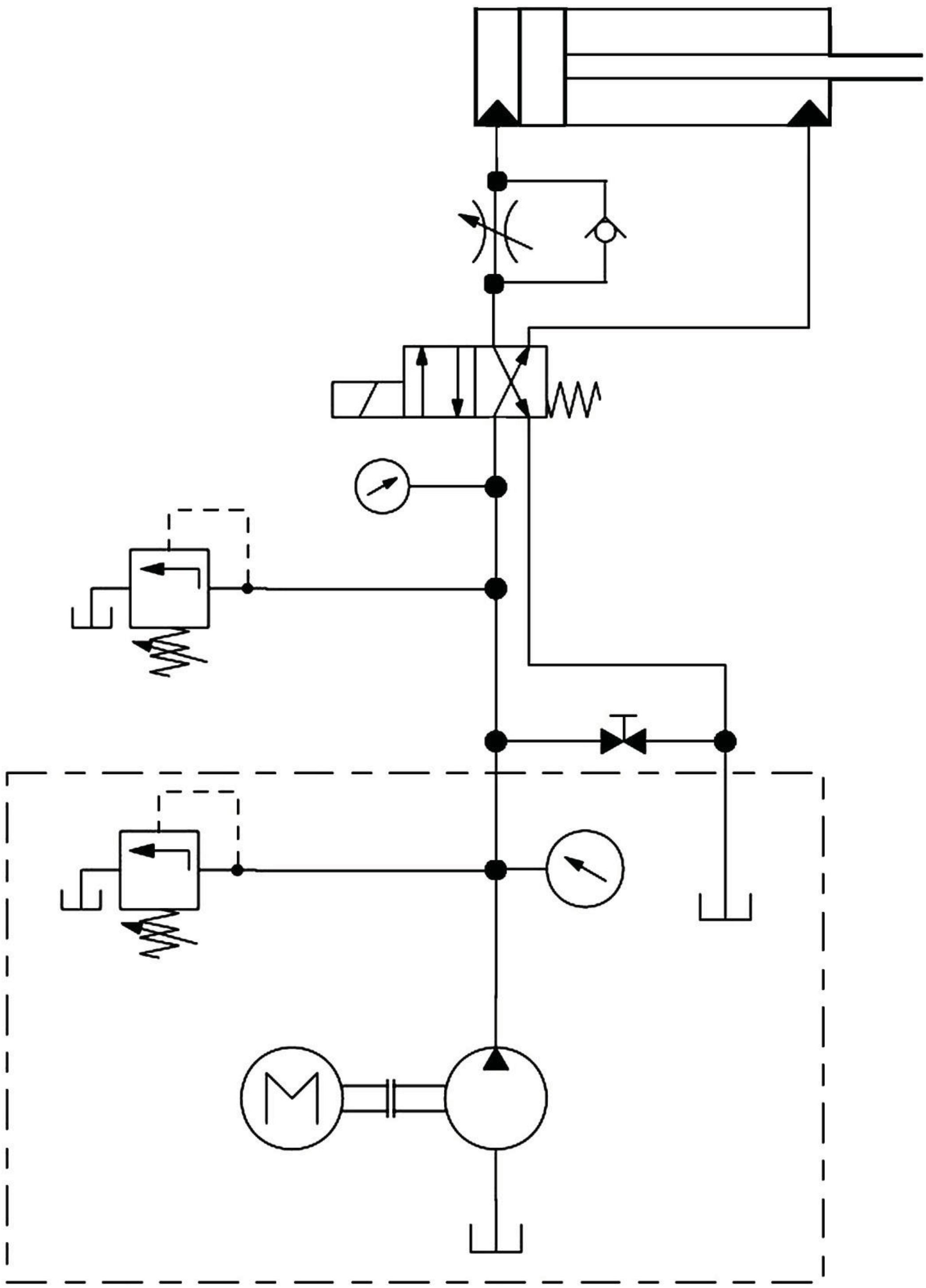
11		
12		
13		
14		

2. Describe the function of the circuit and give a photo of the circuit after assembly



Hydraulic circuit No.2

Hydraulic Circuit No.2

1. Number the elements of the circuit and state the names and function of the circuit parts in the following table

No.	Name	Function
1		
2		
3		
4		
5		
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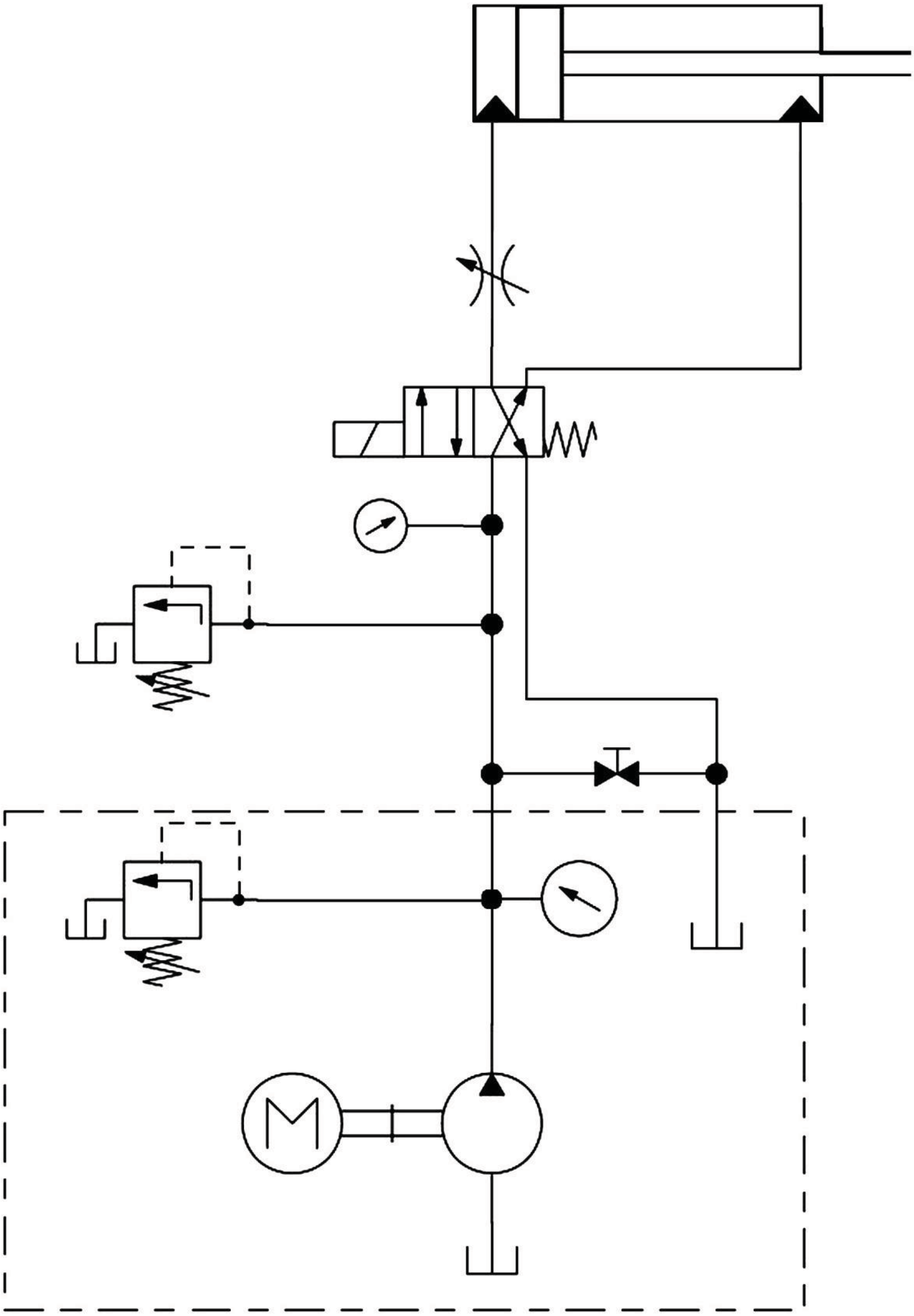
14		

2. Describe the function of the circuit and give a photo of the circuit after assembly



Hydraulic circuit No.3

Hydraulic Circuit No.3

1. Number the elements of the circuit and state the names and function of the circuit parts in the following table

No.	Name	Function
1		
2		
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4		
5		
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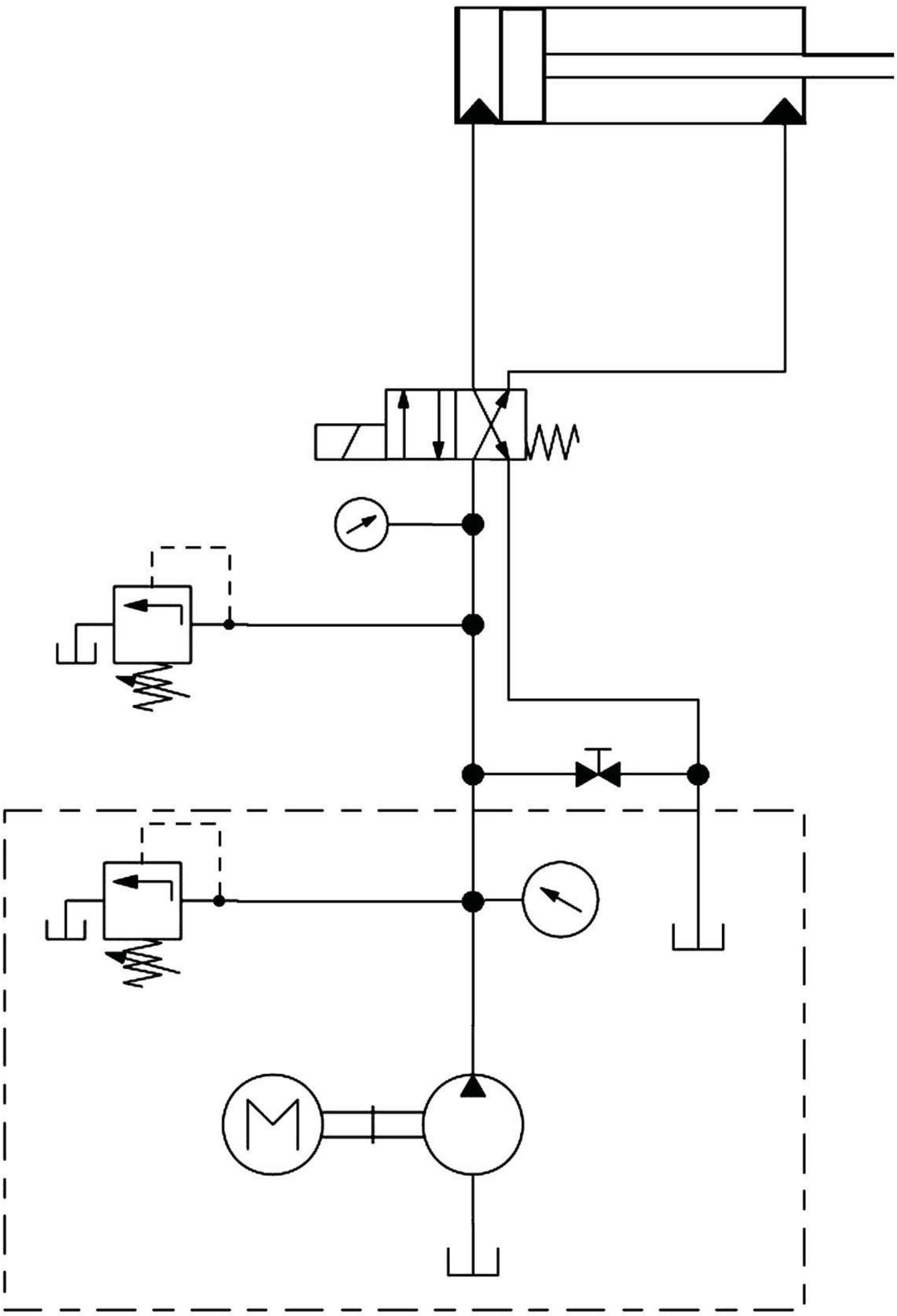
11		
12		
13		
14		

2. Describe the function of the circuit and give a photo of the circuit after assembly



Hydraulic circuit No.4

Hydraulic Circuit No.4

1. Number the elements of the circuit and state the names and function of the circuit parts in the following table

No.	Name	Function
1		
2		
3		
4		
5		
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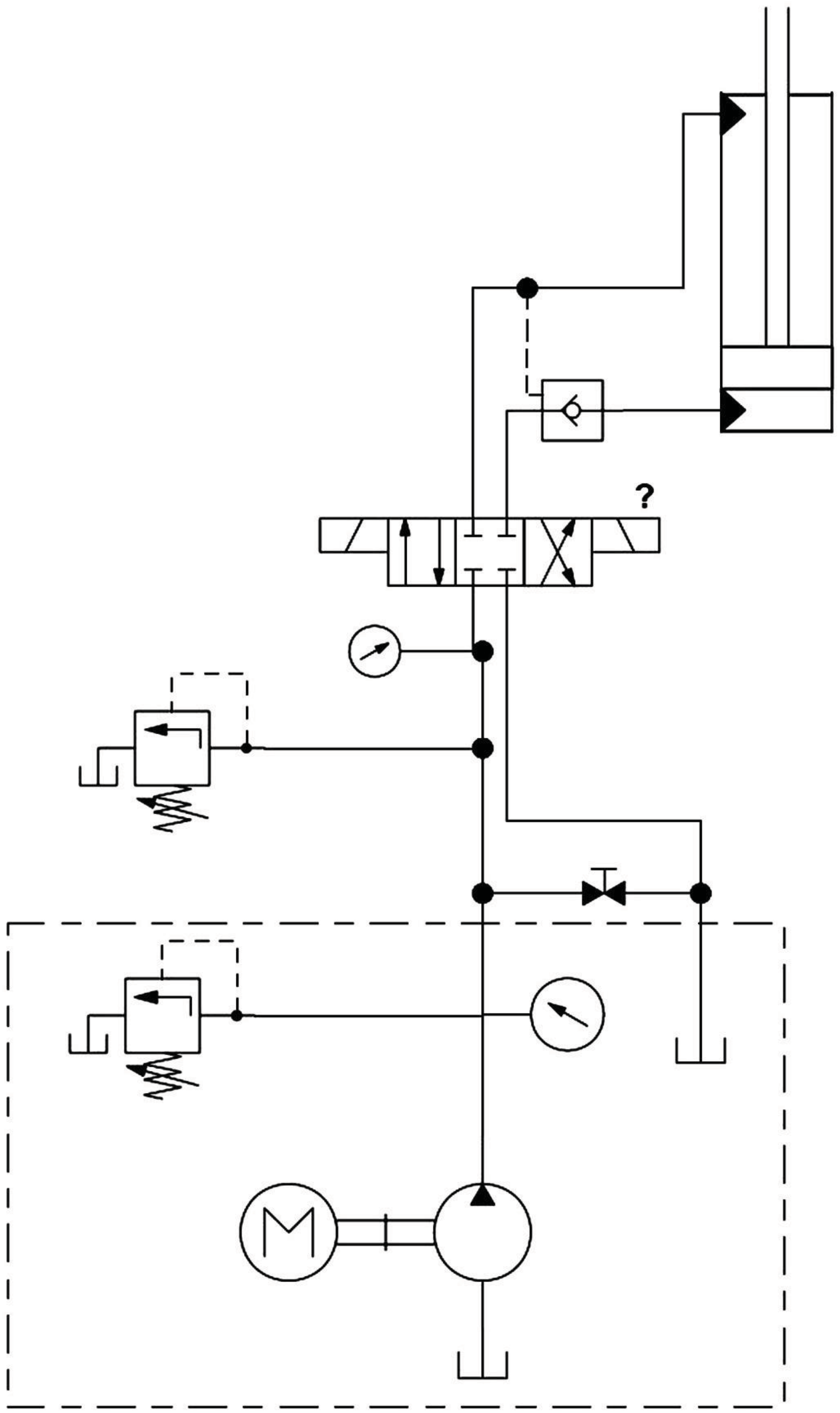
11		
12		
13		
14		

2. Describe the function of the circuit and give a photo of the circuit after assembly



Hydraulic circuit No.5

Hydraulic Circuit No.5

1. Number the elements of the circuit and state the names and function of the circuit parts in the following table

No.	Name	Function
1		
2		
3		
4		
5		
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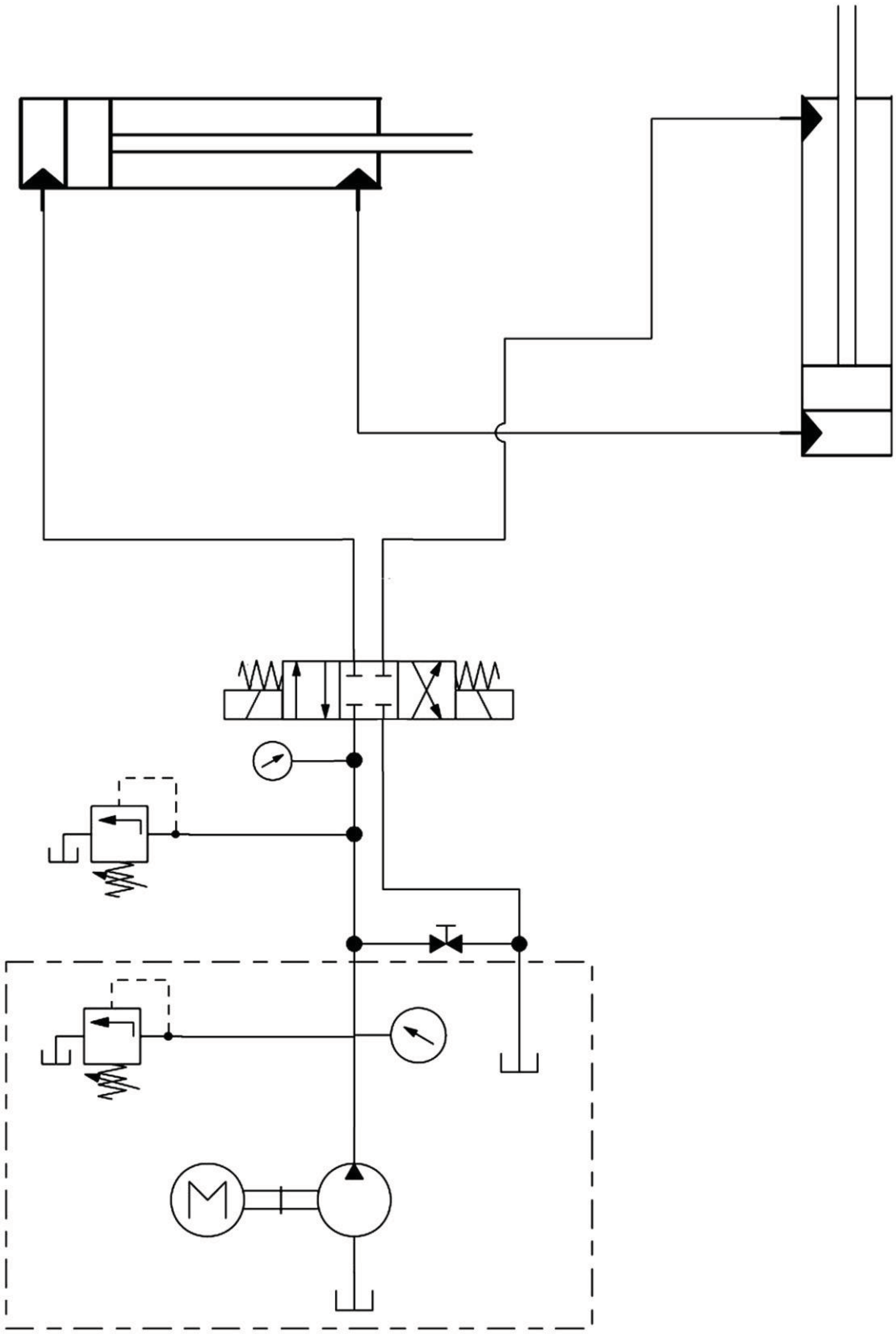
8		
9		
10		
11		
12		
13		
14		

2. Describe the function of the circuit and give a photo of the circuit after assembly



Hydraulic circuit No.6

Hydraulic Circuit No.6

1. Number the elements of the circuit and state the names and function of the circuit parts in the following table

No.	Name	Function
1		
2		
3		
4		
5		
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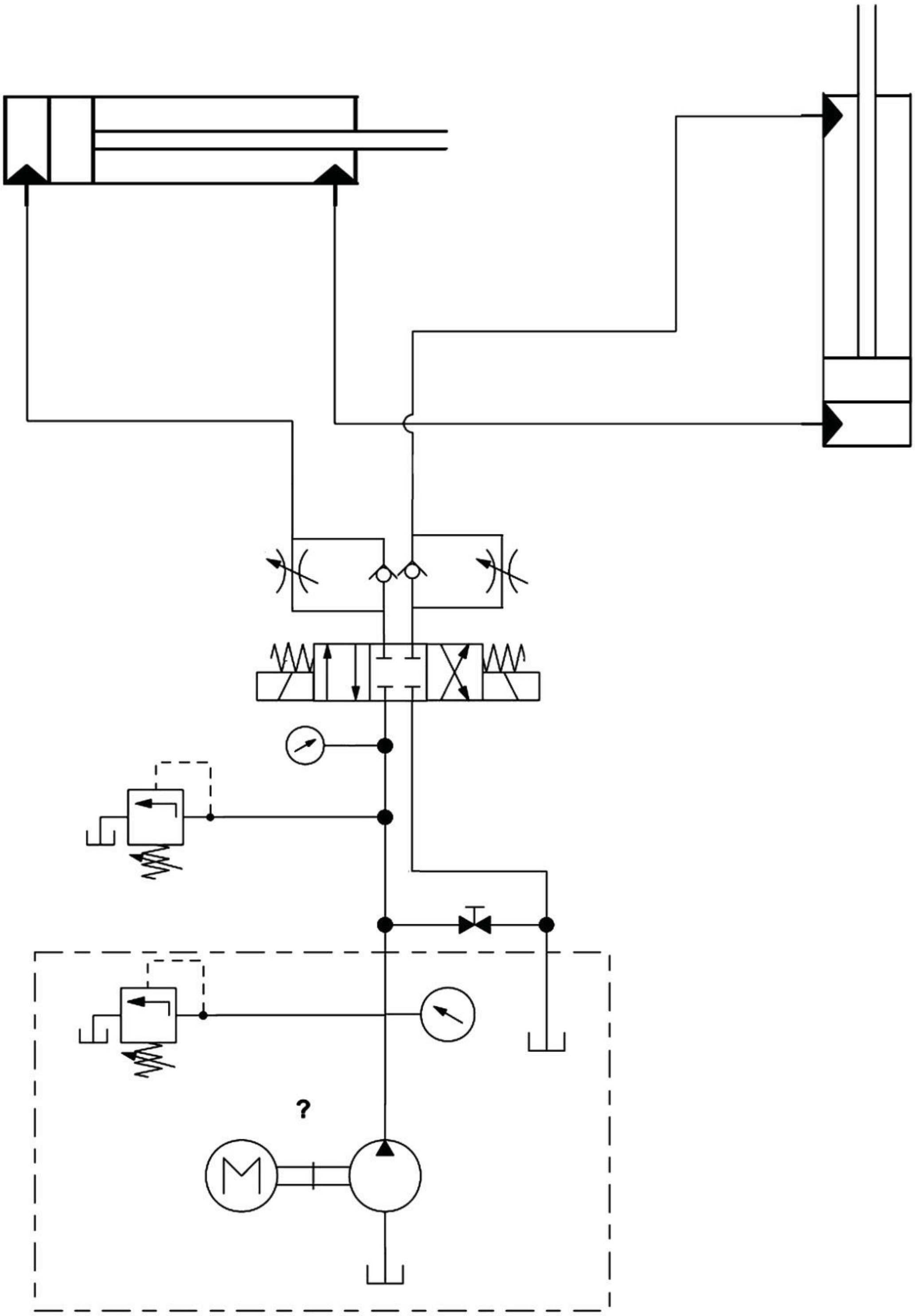
11		
12		
13		
14		

2. Describe the function of the circuit and give a photo of the circuit after assembly



Hydraulic circuit No.7

Hydraulic Circuit No.7

1. Number the elements of the circuit and state the names and function of the circuit parts in the following table

No.	Name	Function
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

2. Describe the function of the circuit and give a photo of the circuit after assembly

Practical Exam Questions

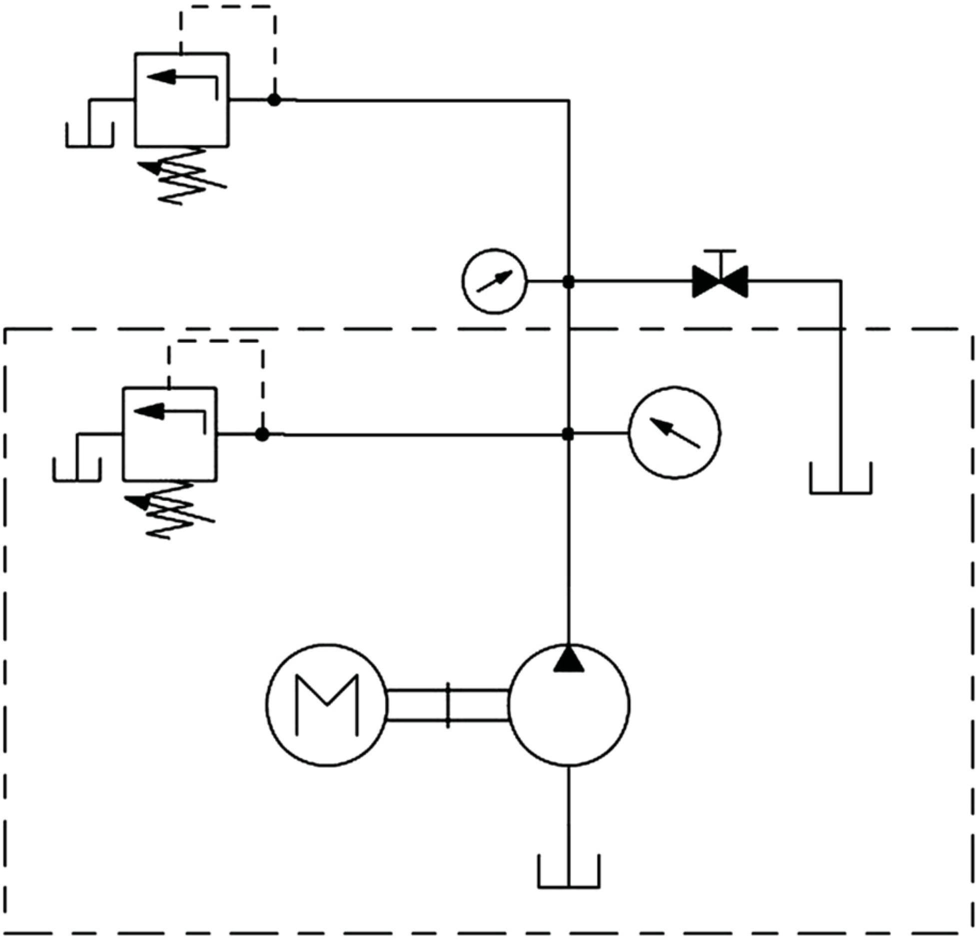
M 578

Fluid Power Engineering

Questions for Practical Examination

Question 1

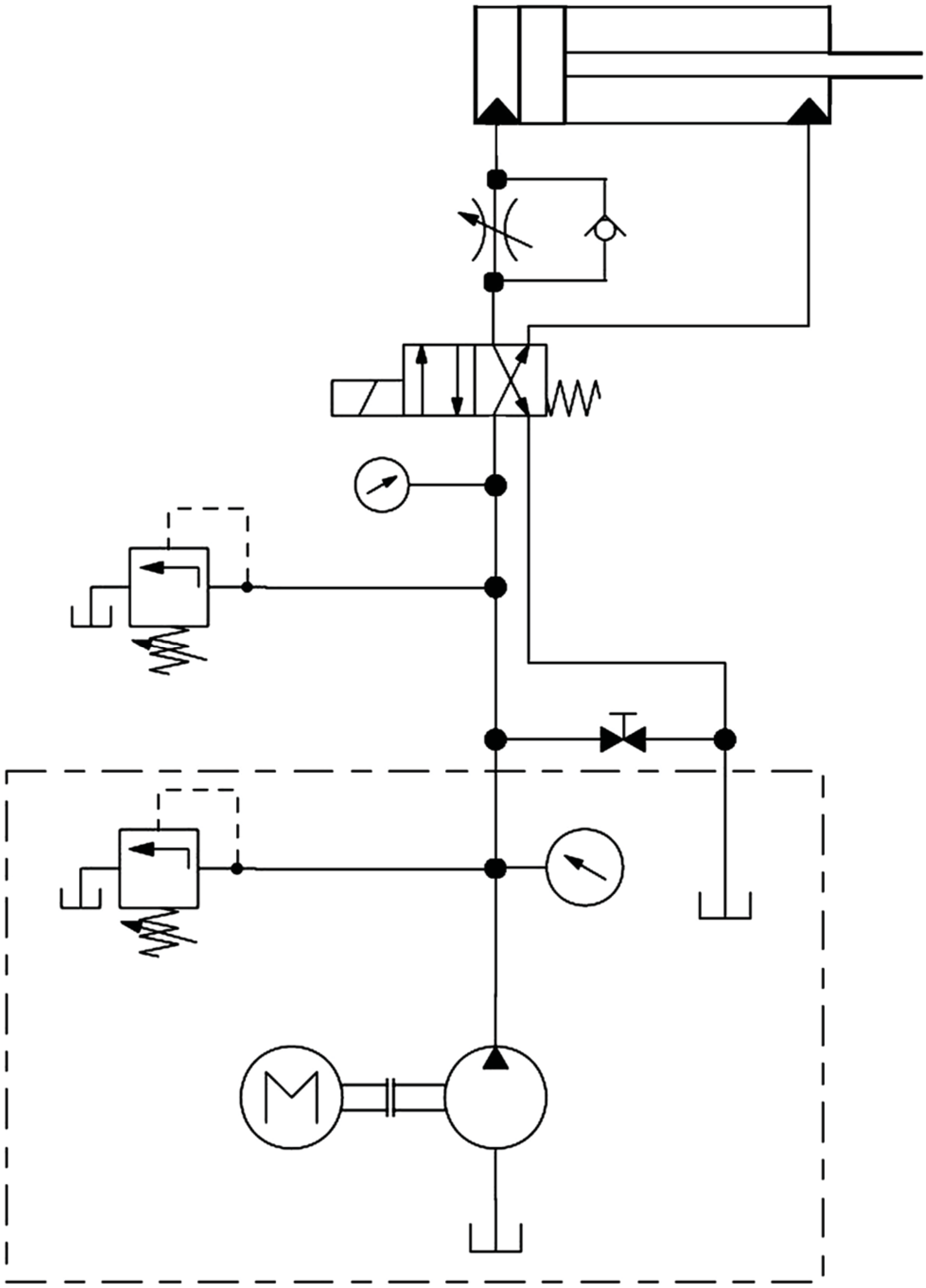
Explain the construction and operation of the shown hydraulic system, assemble this system on the hydraulic training unit and adjust the maximum system pressure to be 35 bar.



Hydraulic circuit No.1

Question 2

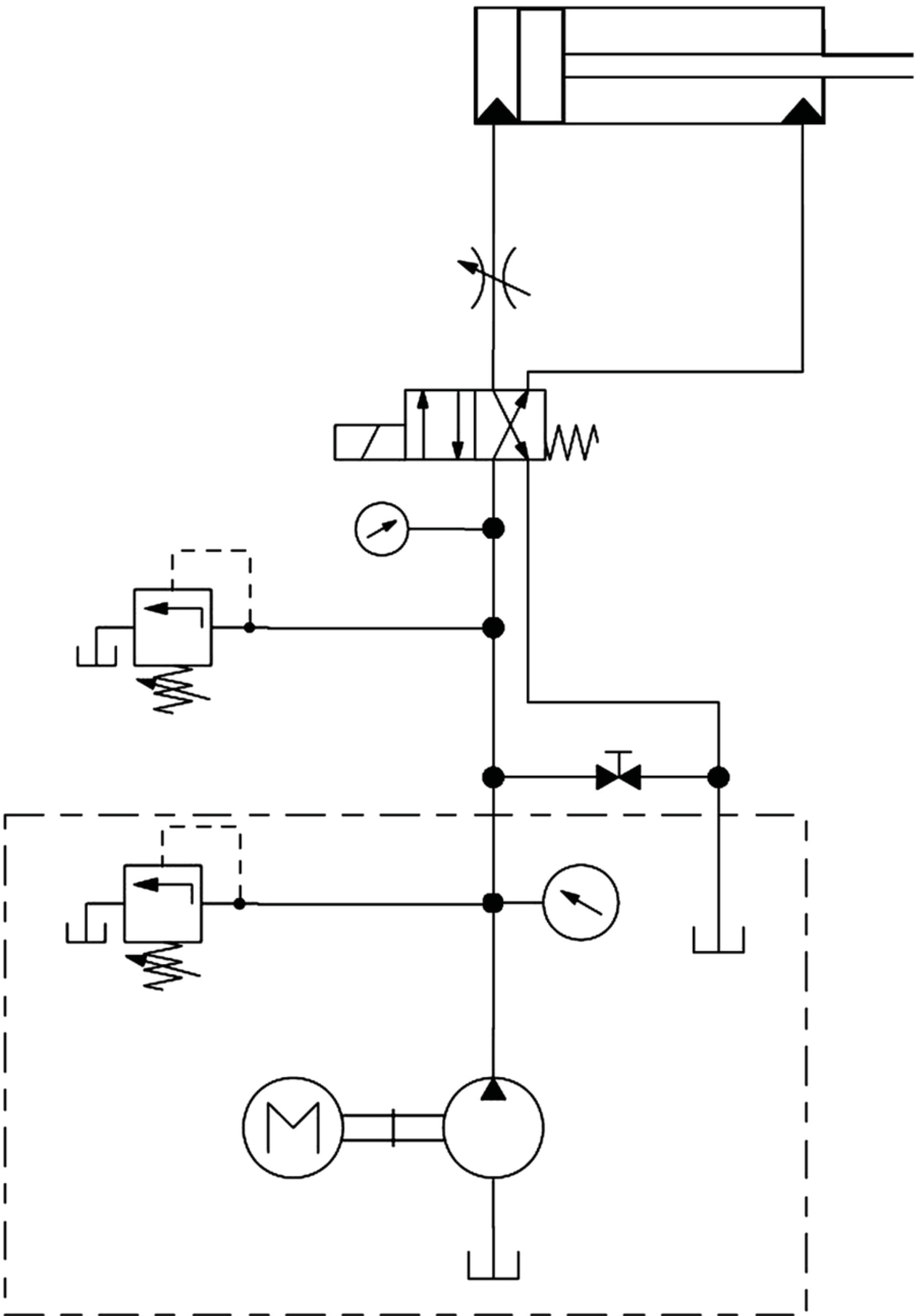
Explain the construction and operation of the shown hydraulic system, assemble this system on the hydraulic training unit and check its different operating modes.



Hydraulic circuit No.2

Question 3

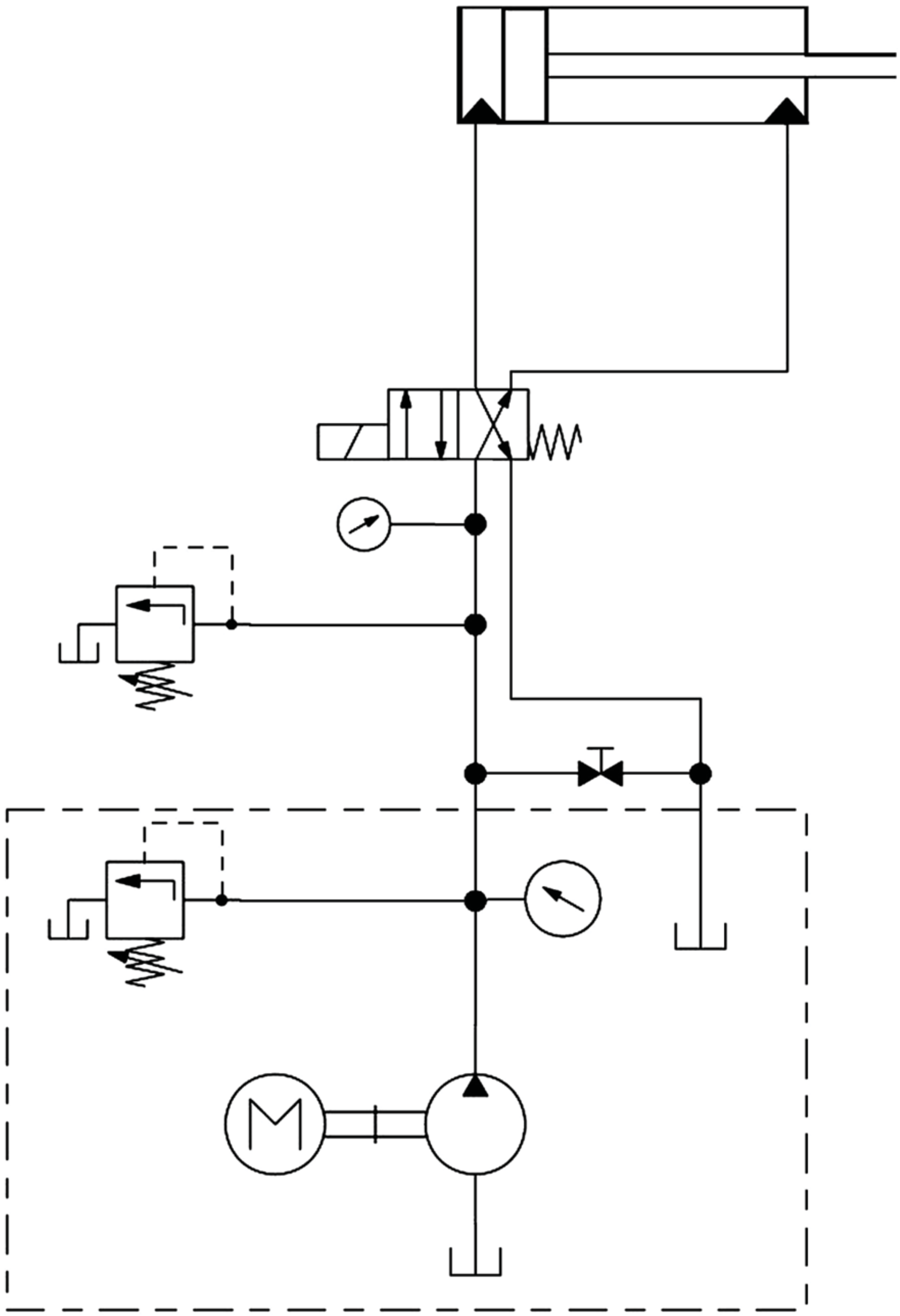
Explain the construction and operation of the shown hydraulic system, assemble this system on the hydraulic training unit and check its different operating modes.



Hydraulic circuit No.3

Question 4

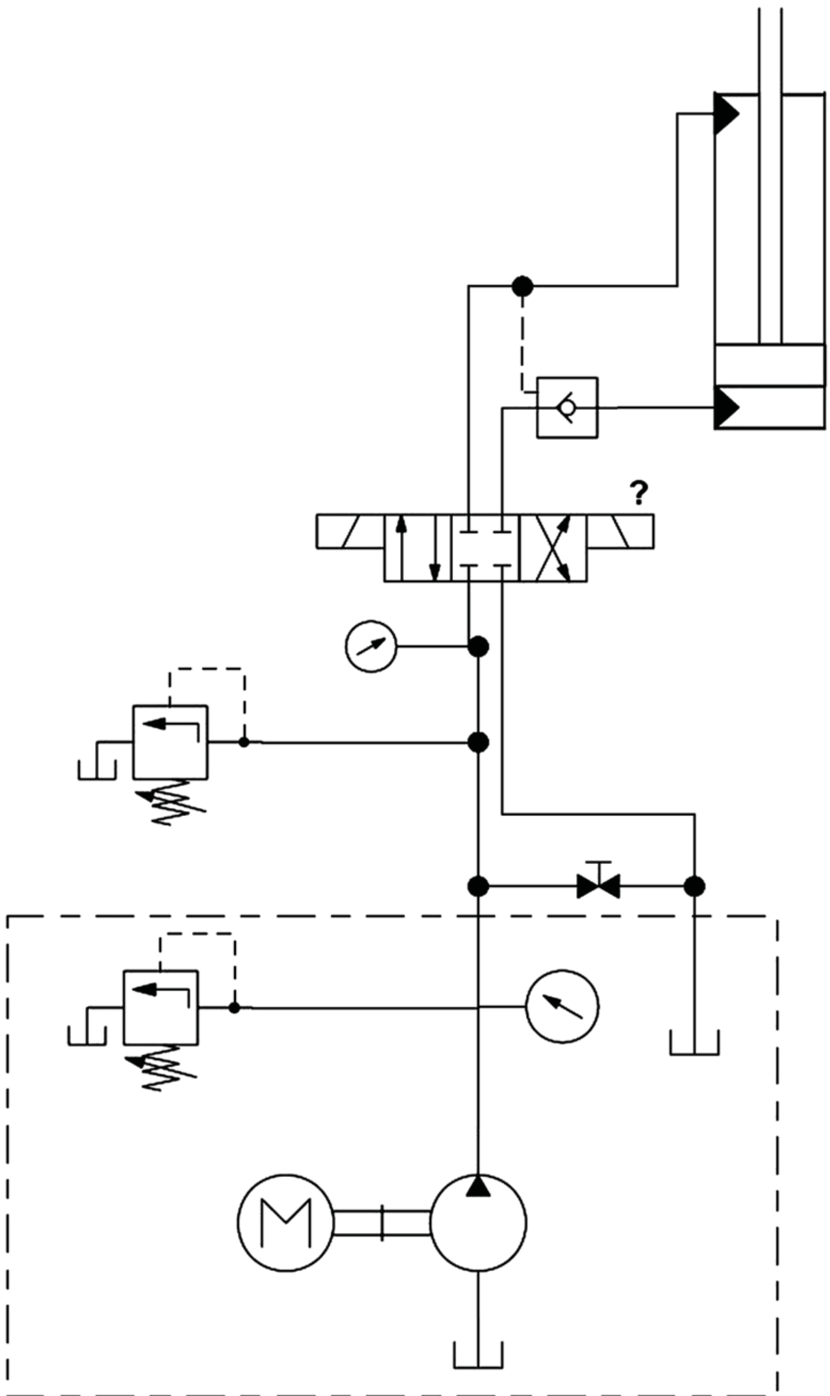
Explain the construction and operation of the shown hydraulic system, assemble this system on the hydraulic training unit and check its different operating modes.



Hydraulic circuit No.4

Question 5

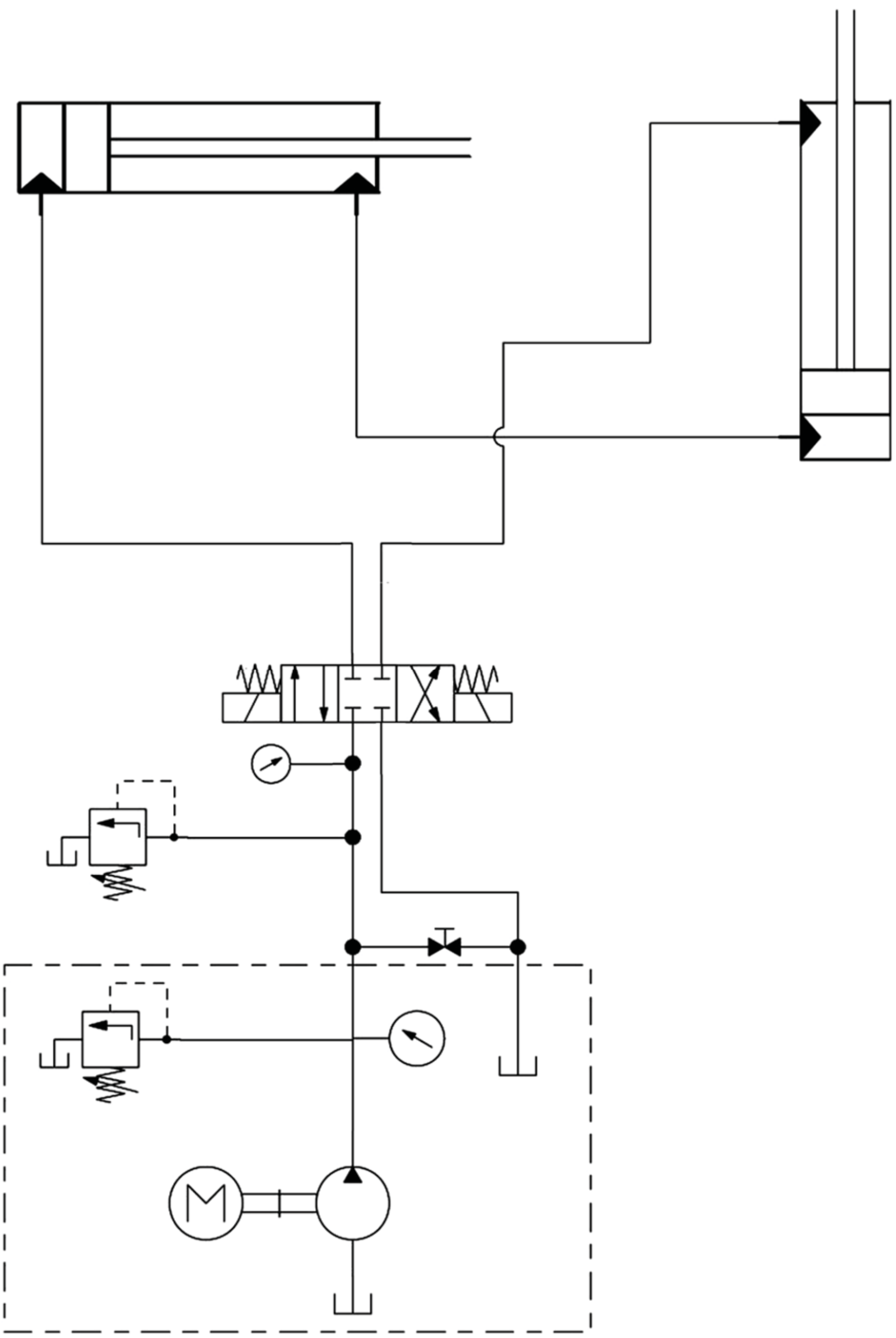
Explain the construction and operation of the shown hydraulic system, assemble this system on the hydraulic training unit and check its different operating modes.



Hydraulic circuit No.5

Question 6

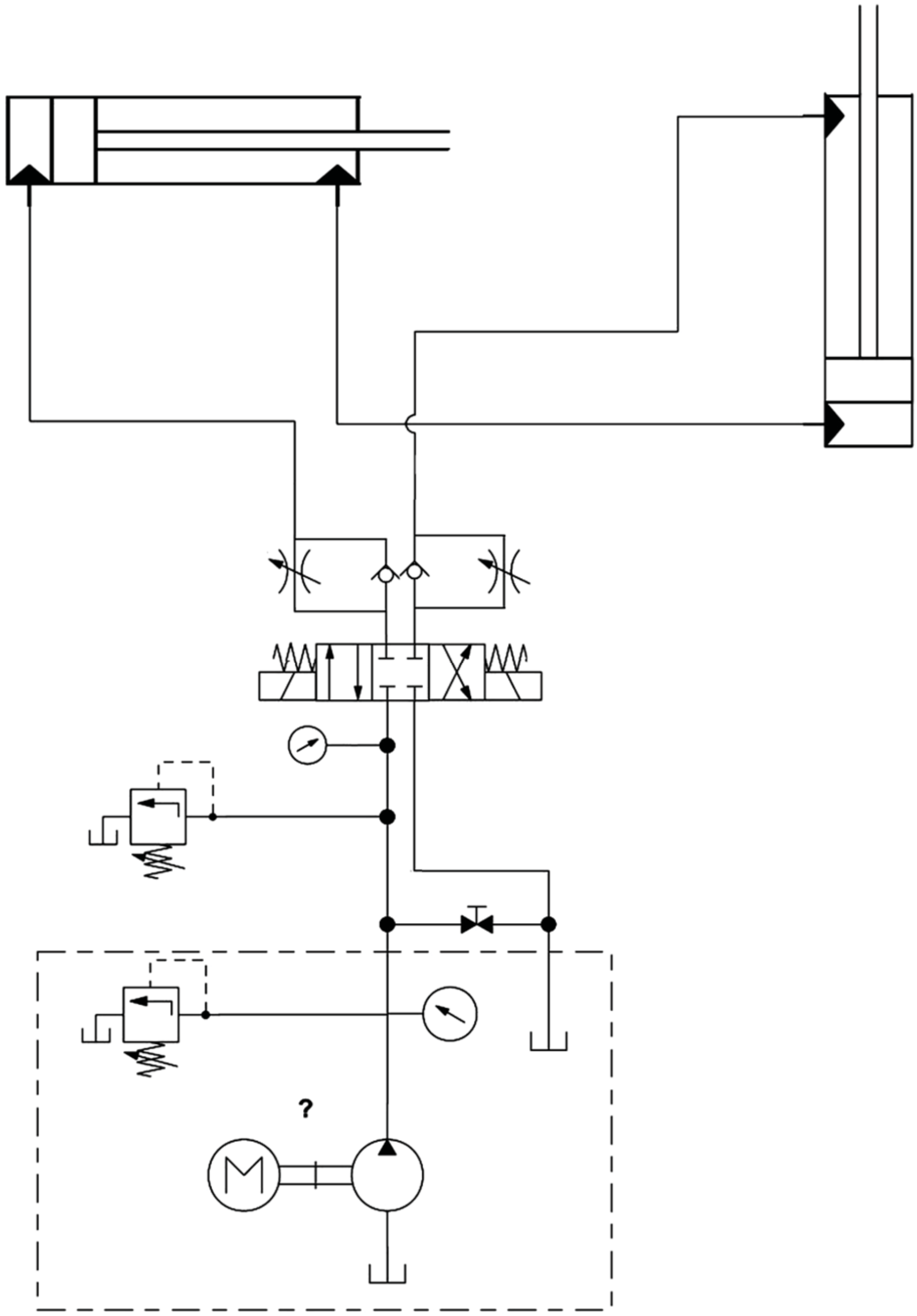
Explain the construction and operation of the shown hydraulic system, assemble this system on the hydraulic training unit and check its different operating modes.



Hydraulic circuit No.6

Question 7

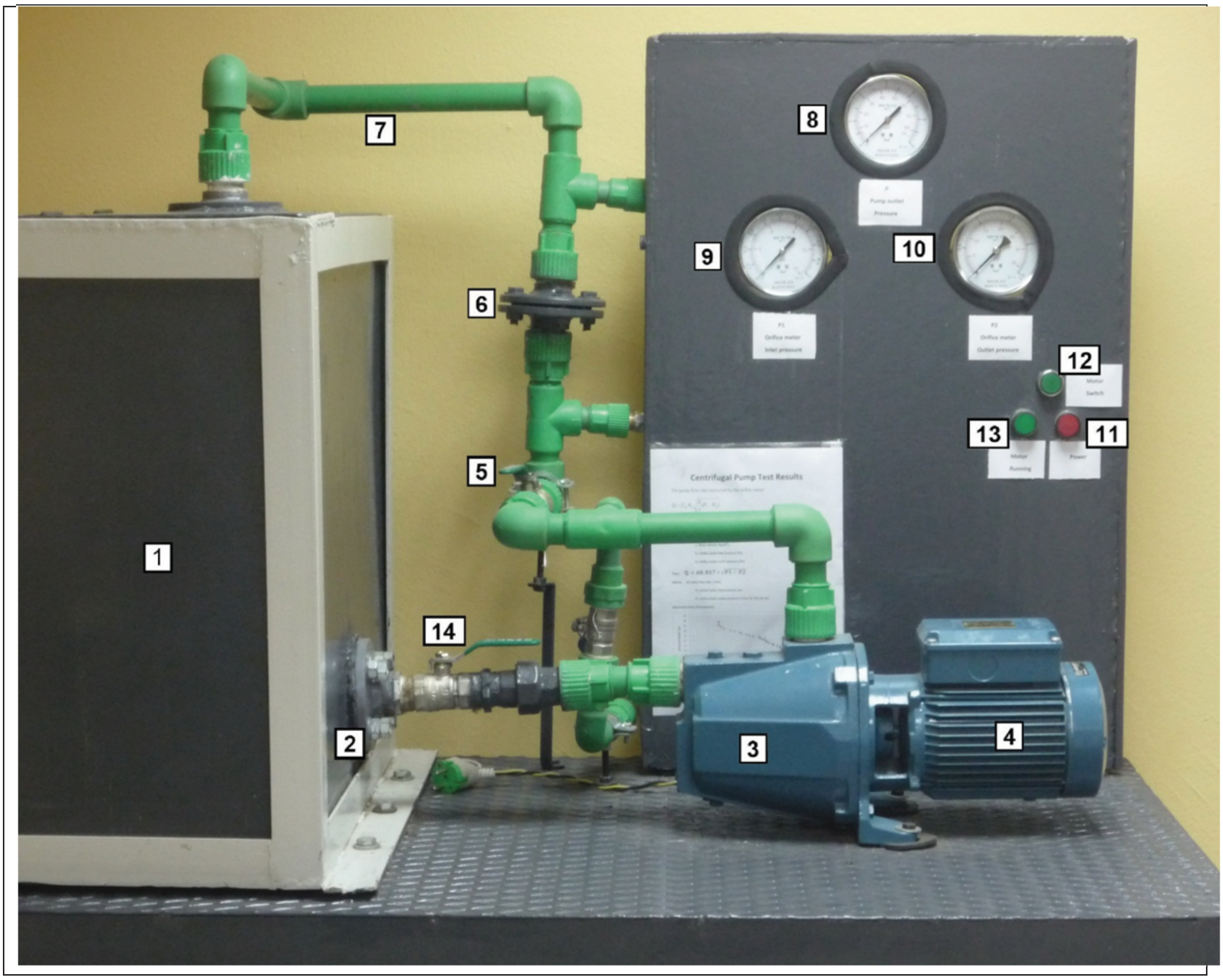
Explain the construction and operation of the shown hydraulic system, assemble this system on the hydraulic training unit and check its different operating modes.



Hydraulic circuit No.7

Question 8

Explain the construction and operation of the shown Centrifugal pump test stand. Put the system in operation and measure the pumping head and corresponding pump flow rate for two different points, then, give a comment on the measured results.



Question 9

- Explain the construction and operation of the shown displacement pumps test stand.
- Explain the visualization of cavitation at the pump inlet line.
- Run the system and show the cavitation at the pump inlet line
- Discuss the origin of this phenomenon, its effects and how to avoid its occurrence.

Question 10

- Explain the construction and operation of the shown displacement pumps test stand.
- Put the system in operation and measure the pumping flow rate for two different values of pump exit pressure, then, give a comment on the measurement results.

Academic Year: 2015-2016

✓	Mid-term exam paper
✓	Model answer for the mid-term exam
NR	Corrective exam paper
NR	Model answer for the corrective exam
✓	Final written exam paper
✓	Model answer for the final written exam
✓	Final written exam evaluation and exam result analysis
x	Students course-questionnaire analysis, the file box contains a hard copy of this document
NR	November exam paper
NR	Model answer for November written exam
✓	Annual course report

✓=Document Exists x=Document doesn't exist NR=Not Relevant

Modern Academy
for Engineering and Technology in Maadi
Manufacturing Engineering and Production
Technology Department

Academic Year	2015-2016
Semester	First
Exam Date	17/11/2015

QUESTIONS FOR THE MID TERM WRITTEN EXAM

Subject: (M578) Hydraulic Power Systems **Spec.:** 5^{th} Man. Eng. & Prod. Tech.
Examiners: Professor M. Galal RABIE & Dr Metwally Hussein **Time:** 90 min

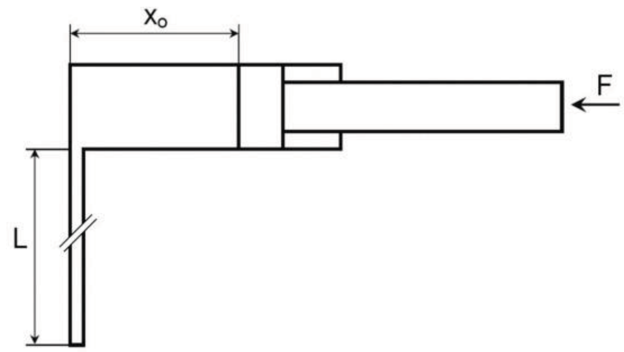
Number of Pages: 1 Number of Questions: 3 Attempt all questions

Question 1 **(8 points)**

(a) Draw the circuit of a simple hydraulic system, including a pump, directional control valve, hydraulic cylinder, relief valve, and other hydraulic components. State the function of the individual elements.

(b) Define the bulk modulus of oil and calculate the shift of the piston in the given system if the force F is increased by 100 kN, given:

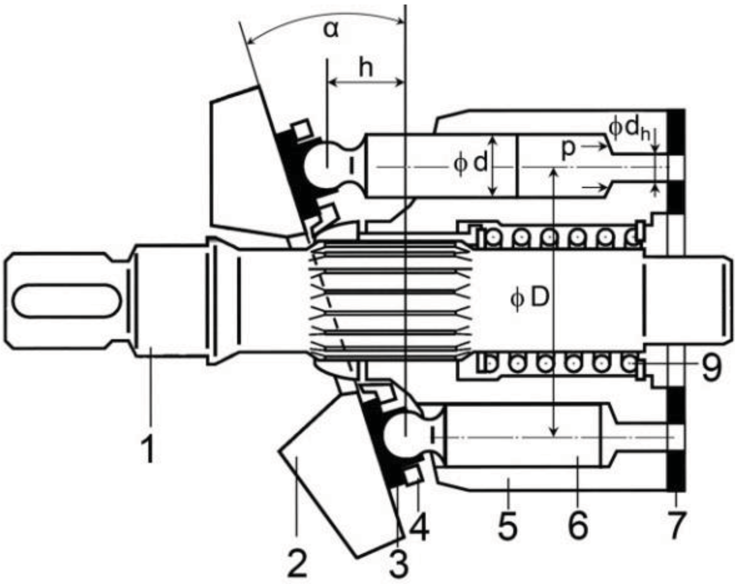
Piston area A_p = .0176 m^2
Pipe line diameter d = 13 mm
Fluid bulk modulus B = 1.4GPa,
Initial displacement x_o = 0.5 m,
Pipe length L = 5 m,



Question 2 **(8 points)**

(a)Derive an expression for the pressure and power losses in a hydraulic transmission line of constant diameter in the case of laminar flow.

(b) Shown is a schematic of a displacement pump. Explain briefly its function and give an expression for its geometric volume.



Question 3 **(4 points)**

Give the expressions describing ideal and real displacement pumps, giving the meaning and units of the used symbols.

Give the meaning and units of all of the used symbols.
The neatness and good organization of your exam paper are evaluated

G O O D L U C K

Modern Academy
for Engineering and Technology in Maadi
Manufacturing Engineering and Production Technology Department

Academic Year 2015-2016
Semester First
Exam Date 17/11/2015

MODEL ANSWER FOR THE MID TERM WRITTEN EXAM

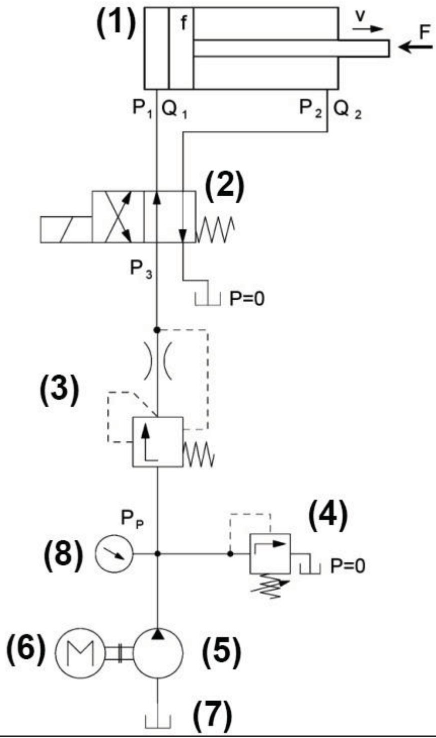
Subject: (M578) Hydraulic Power Systems **Spec.:** 5th Man. Eng. & Prod. Tech.
Examiners: Professor M. Galal RABIE & Dr Metwally Hussein **Time:** 90 min

Number of Pages: 1 Number of Questions: 3 Attempt all questions

Question 1 **(8 points)**

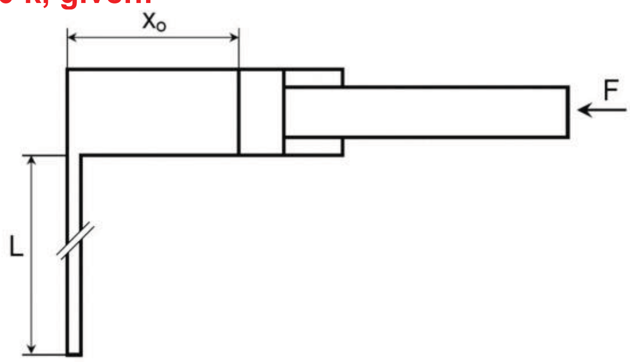
(a) Draw the circuit of a simple hydraulic system, including a pump, directional control valve, hydraulic cylinder, relief valve, and other hydraulic components. State the function of the individual elements.

One of the possible answers



(1) Hydraulic cylinder: Converts the hydraulic power to mechanical power. The input flow rate is converted to the piston speed while the input pressure is converted to the force which drives the load.
(2) Directional control valve: Controls the direction of motion of the cylinder.
(3) Series pressure compensated flow control calve: controls the flow rate, concequently the cylinder speed is controlled.
(4) Relief valve, limiting the maximum system pressure.
(5) Fixed displacement pump: Converts the mechanical power into hydraulic power.
(6) Electric motor: drives the pump, by bsupplying the required mechanical power.
(7)Hydraulic tank: locates the needed hydraulic liquid.
(8) Pressure gauge: Indicates the system pressure.

(b) Define the bulk modulus of oil and calculate the shift of the piston in the given system if the force F is increased by 100 k, given:
Piston area A_p = .0176 m^2
Pipe line diameter d = 13 mm
Fluid bulk modulus B = 1.4GPa,
Initial displacement x_o = 0.5 m,
Pipe length L = 5 m,



The liquid compressibility is defined as the ability of liquid to change its volume when its pressure varies. For pure liquid, the relation between the oil volume and pressure variations is described by the following formula.

$$B = -\frac{\Delta P}{\Delta V / V} = -\frac{dP}{dV/V} \quad \text{or} \quad \frac{B}{V} = -\frac{dP}{dV} = -\frac{dP}{dt} / \frac{dV}{dt} \qquad (2.48)$$

where
ΔP = Pressure variation, Pa
ΔV = Change in volume due to pressure variation, m^3
V = Initial oil volume, m^3
B = Bulk modulus of oil, typically B = 1 to 2 GPa

$$\because B = -\frac{\Delta P}{\Delta V / V}$$

$$\therefore \Delta V = \frac{\Delta P}{B} V$$

$$\Delta P = \frac{F}{A_p}$$

$$\Delta P = \frac{100 \times 10^3}{0.0176} = 5.68 MPa$$

$$V = A_p x_o + \tfrac{\pi}{4} d^2 L = 0.0176 \times 0.5 + \tfrac{\pi}{4} \times 0.013^2 \times 5 = 9.463 \times 10^{-3} m^3$$

$$\Delta V = \frac{5.68 \times 10^6}{1.4 \times 10^9} \times 9.463 \times 10^{-3} = 3.84 \times 10^{-5} m^3$$

And $\Delta V = z A_p$

$$z = \frac{\Delta V}{A_p} = \frac{3.84 \times 10^{-5}}{0.0176} = 2.18 mm$$

Question 2 (8 points)

(a) Derive an expression for the pressure and power losses in a hydraulic transmission line of constant diameter in the case of laminar flow.

In hydraulic transmission lines, the flow may be laminar or turbulent depending on the ratio of the inertia forces to the viscous friction forces. This ratio is evaluated by the Reynolds number, **Re**. For laminar flow, Fig.2.4, the pressure losses in the line are calculated from the following relation, Appendix 2B.

$$\Delta P = \lambda \frac{L}{D} \frac{\rho v^2}{2} \tag{2.4}$$

$$v = 4Q / \pi D^2 \tag{2.5}$$

$$\lambda = 64 / Re \tag{2.6}$$

$$Re = vD / \nu = \rho v D / \mu \tag{2.7}$$

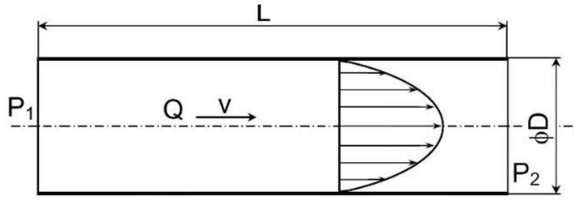
where
- D = Inner pipe diameter, m.
- L = Pipe length, m
- Re = Reynolds number
- v = Mean fluid velocity, m/s
- ΔP = Pressure losses in the pipe line, Pa
- λ = Friction coefficient for laminar flow
- ρ = Oil density, kg/m^3

The following expression for the pressure losses ΔP was obtained by substituting Eqs. 2.5 to 2.7 in Eq.2.4.

$$\Delta P = \frac{128 \mu L}{\pi D^4} Q = R\, Q \tag{2.8}$$

The term **R** expresses the resistance of the hydraulic transmission line. Its effect is equivalent to that of the electric resistance. Both of them dissipate energy and both are described by the same mathematical relation ($e = Ri$). The power loss ΔN in the pipeline is given by:

$$\Delta N = QP_1 - QP_2 = Q\,\Delta P = RQ^2 = \frac{128 \mu L}{\pi D^4} Q^2 \tag{2.9}$$



Laminar flow in pipeline

(b)Shown is a schematic of a displacement pump. Explain briefly its function and give an expression for its geometric volume.

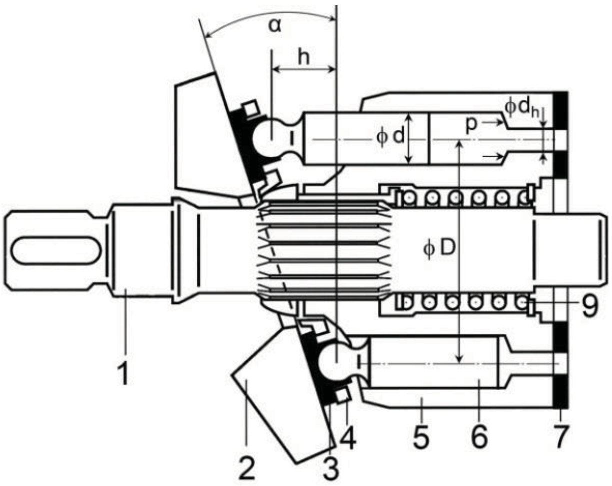


Figure 4.16 shows the construction and operation of a swash plate pump. The drive shaft **1** rotates and drives the cylinder block **5**. Both of the driving shaft and the cylinder block have the same axis of rotation. The cylinder block and its pistons **6**, rotate with the drive shaft. Each of the pistons is attached to a slipper pad **3**. The pistons and their slipper pads are inserted in the holes of the retaining plate **4**. Therefore, the retaining plate rotates with the pistons and the cylinder block. It is guided to rotate in a plane parallel to the swash plate **2**, by a fixed guide. The trajectory of the slipper pad is determined by the swash plate and the retaining plate. During rotation, each piston performs a reciprocating motion. During this process, a volume of fluid, corresponding to the piston area and stroke, is sucked or delivered via both control openings in the port plate **7**.
The cylinder block is pushed against the port plate by means of a spring **9**, which minimizes the leakage through the clearance separating them at the beginning of the pump operation. When the pressure builds up, it acts on the cylinder block by a tightening force given by {$0.25\pi(d^2 - d_h^2)P$}. This force acts to the right, against the repulsion force due to the pressure distribution in the clearance between the cylinder block and the port plate. The resultant force acts to reduce this clearance and minimize the leakage through it. The pump geometric volume is given by the following expression:

$$V_g = \frac{\pi}{4} d^2 Dz \tan\alpha \qquad (4.25)$$

where
- d = Piston diameter, m.
- D = Pitch circle diameter, m
- α = Swash plate inclination angle, rad

Question 3 **(4 points)**

Give the expressions describing ideal and real displacement pumps, giving the meaning and units of the used symbols.

IDEAL PUMP

The pump **displacement** is defined as the volume of liquid delivered by the pump per revolution, assuming no leakage and neglecting the effect of oil compressibility. It depends on the maximum and minimum values of the pumping chamber volume, the number of pumping chambers and the number of pumping strokes per one revolution of the driving shaft. This volume depends on the pump geometry; therefore, it is also called **geometric volume V_g**. It is given by the following equation.

$$V_g = (V_{max} - V_{min})zi \qquad (4.1)$$

Where
- i = Number of pumping strokes per revolution.
- V_g = Pump displacement (geometric volume), m^3/rev.
- V_{max} = Maximum chamber volume, m^3.
- V_{min} = Minimum chamber volume, m^3.

z = Number of pumping chambers.

Assuming ideal pump; with no internal leakage no friction and no pressure losses, the pump flow rate is given by the following expression.

$$Q_t = V_g n \tag{4.2}$$

where Q_t = Pump theoretical flow rate, m^3/s.

n = Pump speed, rev/s.

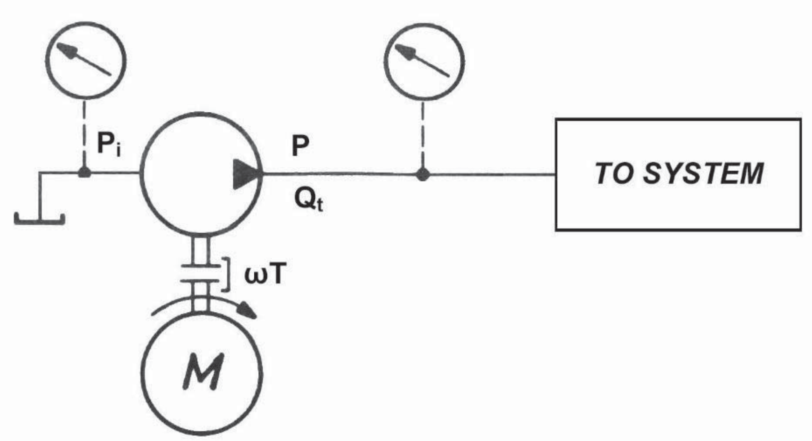


Fig.4.2 Typical displacement pump connection in hydraulic power circuits

Following the assumption of ideal pump, the input mechanical power is equal to the increase in the fluid power as shown by the following equation, Fig.4.2.

$$2\pi n T_t = Q_t(P - P_i) = V_g n \Delta p \tag{4.3}$$

Or $$T_t = \frac{V_g}{2\pi}\Delta P \tag{4.4}$$

where T_t = Pump theoretical driving torque, Nm.

ΔP = Pressure increase due to pump action, Pa.

REAL PUMP

$$\eta_T = \eta_v \, \eta_m \, \eta_h \tag{4.11}$$

In the steady state operation, the real displacement pump is described by the following relations.

$$Q = V_g n \eta_v \tag{4.12}$$

$$N_h = N_m \eta_T \quad \text{Or} \quad Q\Delta P = 2\pi n T \eta_T \tag{4.13}$$

Then $$T = \frac{V_g}{2\pi \eta_m \eta_h}\Delta P \tag{4.14}$$

where η_T = Total Efficiency

η_v = Volumetric Efficiency

η_m Mechanical Efficiency

η_h Hydraulic Efficiency

Modern Academy

for Engineering and Technology in Maadi
Manufacturing Engineering and Production Technology Department

Academic Year	2015-2016
Semester	First
Exam Date	11/1/2016

QUESTIONS FOR THE FINAL WRITTEN EXAM

Subject: (M578) Hydraulic Power Systems **Spec.:** 5th Man. Eng. & Prod. Tech.
Examiners: Prof. M. Galal Rabie & Dr. Abdelmegid Abdellatif **Time:** 3 hours

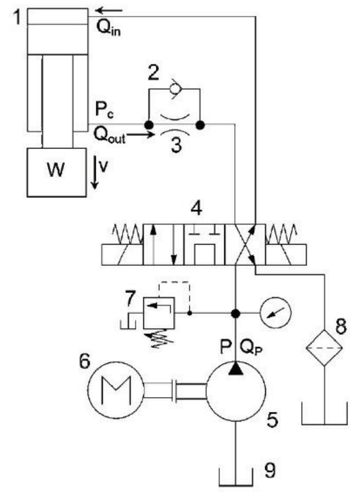
Number of Pages: 2 Number of Questions: 4 Attempt all questions

Question 1 **(25 points)**

(a) i. Give the names of each of the elements of the given system and explain the function of each of them.

ii. Explain the operation of the system in each of the positions of the directional control valve. Use short simple sentences.

iii. Calculate the pressure in the cylinder rod side $\mathbf{P_C}$, the inlet flow rate $\mathbf{Q_{in}}$, outlet flow rate $\mathbf{Q_{out}}$, pump flow rate $\mathbf{Q_P}$, pump output power $\mathbf{N_h}$ and area of the throttle valve $\mathbf{A_t}$. Neglect the hydraulic losses in the system elements, except the throttle valve given: Pump exit pressure = 30 bar, piston speed = 0.07 m/s, piston area A_P = 78.5 cm^2, piston rod-side area A_r = 40 cm^2, oil density = 870 kg/m^3, discharge coefficient = 0.611, the safety valve is pre-set at 350 bar and the weight of the body = 30 kN



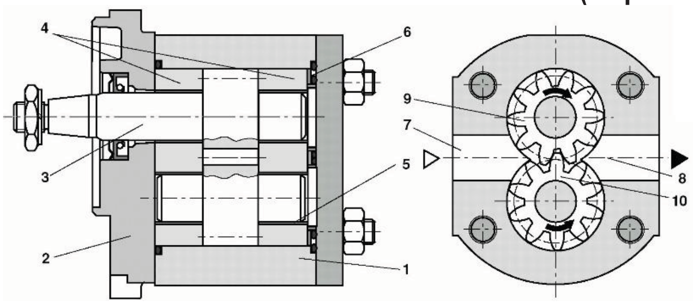
(b) i. State the function of the power systems.

ii. Discuss briefly the principle of operation of the hydraulic and electric power systems giving the advantages and disadvantages of hydraulic power systems. Draw the necessary schemes.

Question 2 **(25 points)**

a) i. Explain briefly the construction and operation of the given pump.

ii. Write an expression for the geometric volume (displacement) of this pump, giving the meaning and units of all of the used symbols.



b) Calculate the displacement volume, input power, leakage flow rate, resistance to internal leakage and driving torque of a gear pump of the following parameters.

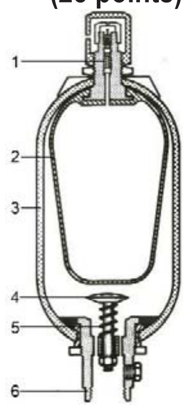
Pump speed =1450 rpm, number of teeth = 12, tooth module = 3.5 mm, Tooth width = 20 mm, pressure angle = 20^o, inlet pressure = 0.2 MPa, exit pressure = 15 MPa, mechanical efficiency = 0.85 and volumetric efficiency = 0.9. Calculate the volumetric efficiency if the pressure is increased to 220 bar.

Question 3 **(25 points)**

a) i. Explain the construction and operation of the given accumulator.

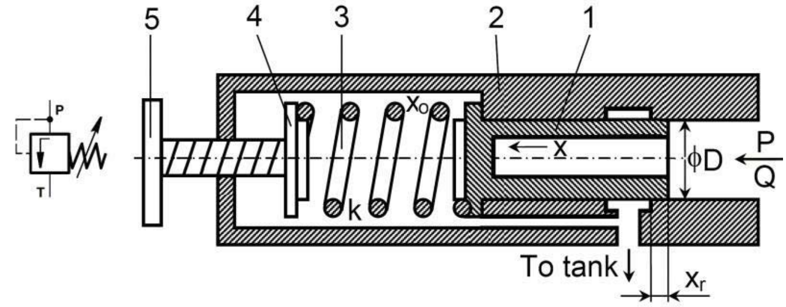
ii. Define the volumetric capacity of hydraulic accumulator.

iii. Derive an expression for the accumulator volumetric capacity.



b) i. Explain the construction and operation of the shown valve.

ii. Derive an equation for the valve flow rate then draw and discuss its flow-pressure characteristics. Explain how to reduce the over-ride pressure.

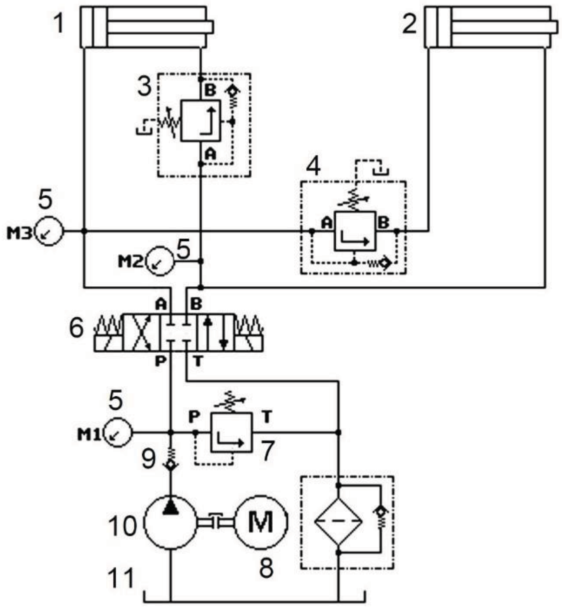


Question 4 **(25 points)**

a) State the applications of hydraulic accumulators in hydraulic systems.

b) Write the equations describing the steady state operation of hydraulic motors.

c) Explain the construction and operation of the given hydraulic circuit.



Give the meaning and units of all of the used symbols.
The neatness and good organization of your exam paper are evaluated
G O O D L U C K

Modern Academy
for Engineering and Technology in Maadi
Manufacturing Engineering and Production
Technology Department

Academic Year	2015-2016
Semester	First
Exam Date	11/1/2016

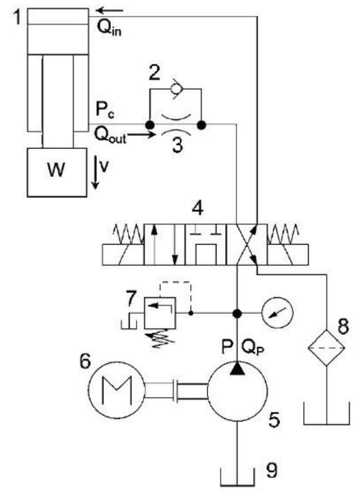
MODEL ANSWER FOR THE FINAL WRITTEN EXAM

Subject: (M578) Hydraulic Power Systems **Spec.:** 5^{th} Man. Eng. & Prod. Tech.
Examiners: Prof. M. Galal Rabie & Dr. Abdelmegid Abdellatif **Time:** 3 hours

Number of Pages: 2 Number of Questions: 4 Attempt all questions

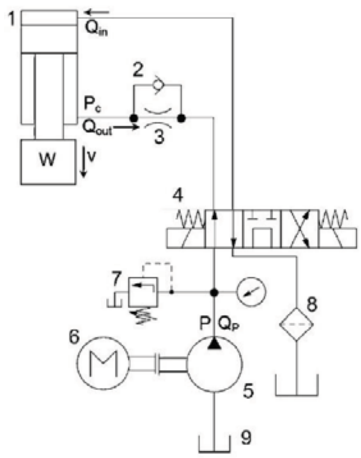
Question 1 (25 points)

(a) i. Give the names of each of the elements of the given system and explain the function of each of them.

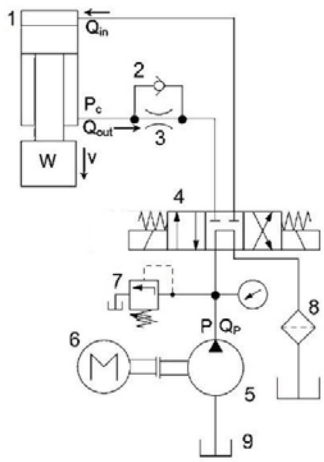


1. Single-rod double-acting hydraulic cylinder, converts the hydraulic power into mechanical power. It acts to lift and lower the driven load.
2. Check valve, allows for free fluid flow into hydraulic cylinder and prevents the flow in the opposite direction.
3. Throttle valve, restricts the fluid flow.
4. 4/3 directional control valve. Controls the direction of motion of hydraulic cylinder.
5. Pump, Converts the mechanical power into hydraulic power.
6. Electric motor, drives the pump.
7. Relief valve, limiting the maximum operating pressure.
8. Hydraulic filter, filters the hydraulic oil returning to tank
9. Hydraulic tank, locates the operating oil.

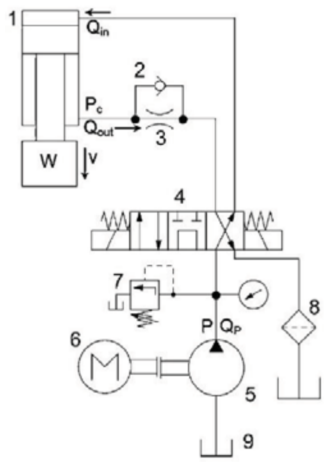
ii. Explain the operation of the system in each of the positions of the directional control valve. Use short simple sentences.



The oil flow from the pump to the DCV, then freely throuch the check valve, into the rod-side of the cylinder. The oiston moved upwards, lifting the load. Then, the oil flows from the piston sidr, thru the DCV and filter, to the hydraulic tank.



In the neutral position, the DCV closes the cylinder ports, traping the oil in the cylinder and holding the load position. It by-passes the pump, minimizing the pump delivery pressure.



The fluid flows from the pump to the piston chamver. The cylinder extends, lowering the load. The oil returning from the cylinder rod-side flows throurg the throttle valve to the DCV, filter, to the tank. The throttling element creates the necessary back pressure which supports the load. It controlls the oilo flow rate, and consequently the load lowering speed.

iii. Calculate the pressure in the cylinder rod side **Pc**, the inlet flow rate **Qin**, outlet flow rate **Qout,** pump flow rate **QP**, pump output power **Nh** and area of the throttle valve **At**. Neglect the hydraulic losses in the system elements, except the throttle valve given: Pump exit pressure = 30 bar, piston speed = 0.07 m/s, piston area A_P = 78.5 cm^2, piston rod-side area A_r = 40 cm^2, oil density = 870 kg/m^3, discharge coefficient = 0.611, the safety valve is pre-set at 350 bar and the weight of the body = 30 kN

$$P_c = (W + PA_p)/A_r = 13.4 MPa$$
$$Q_p = vA_p = 0.00055 m^3/s$$
$$Q_{in} = Q_p = 0.00055 m^3/s$$
$$Q_{out} = vA_r = 0.00028 m^3/s$$
$$A_t = Q_{out}/(C_d\sqrt{2P_c/\rho}) = 2.61 mm^2$$
$$N_h = PQ_p = 1649 W$$

	Input	Name	Output
	30000	W	
	3000000	P	
	.00785	Ap	
	.004	Ar	
	.07	v	
	.611	Cd	
Rule	870	ro	
Pc=(W+P*Ap)/Ar		Pc	13387500
Qp=v*Ap		Qp	.0005495
Qin=Qp		Qin	.0005495
Qout=v*Ar		Qout	.00028
At=Qout/(Cd*(2*Pc/ro)^0.5)		At	2.61223E-6
Nh=P*Qp		Nh	1648.5

(b) i. State the function of the power systems.

The power systems are used to transmit and control power.

ii. Discuss briefly the principle of operation of the hydraulic and electric power systems giving the advantages and disadvantages of hydraulic power systems. Draw the necessary schemes.

Electrical Power Systems

Electrical power systems solve the problems of power transmission distance and flexibility, and improve the controllability. Figure 1.4 illustrates the principal of operation of electrical power systems. These systems have the advantages of high flexibility and very long power transmission distance. But they produce mainly rotary motion. Rectilinear motion, of high power, can be obtained by converting the rotary motion into rectilinear motion by using suitable gear system or by using a drum and wire. However, holding the load position requires special braking system.

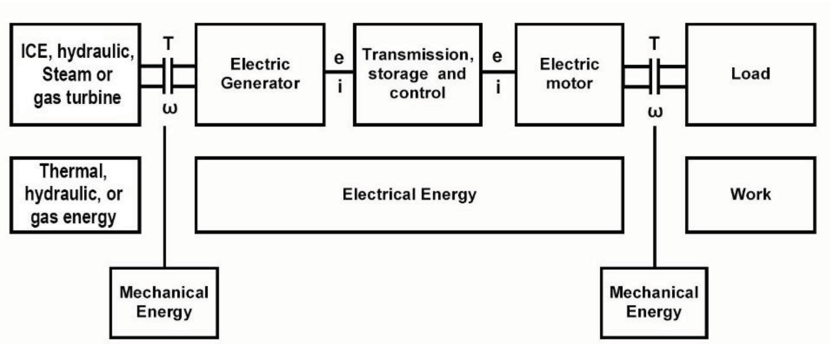


Fig.1.4 Power Transmission in Electrical Power System

Hydraulic Power Systems

In the hydrostatic power systems, the power is transmitted by increasing mainly the pressure energy of liquid. These systems are widely used in industry, mobile equipment, aircrafts, ship control ...etc. This text deals with the hydrostatic power systems, which are commonly called **hydraulic power systems**.

The function of this system is summarized in the following.

1. The prime mover supplies the system with the required mechanical power. The pump converts the input mechanical power to hydraulic power.

2. The energy-carrying liquid is transmitted through the hydraulic transmission lines; pipes and hoses. The hydraulic power is controlled by means of valves of different types. This circuit includes three different types of valves, a pressure control valve, a directional control valve and a flow control (throttle-check) valve.

3. The controlled hydraulic power is communicated to the hydraulic cylinder (or motor) which converts it to the required mechanical power. Generally, the hydraulic power systems provide both of rotary and linear motions.

Figure 1.8 gives the principal of operation of such systems.

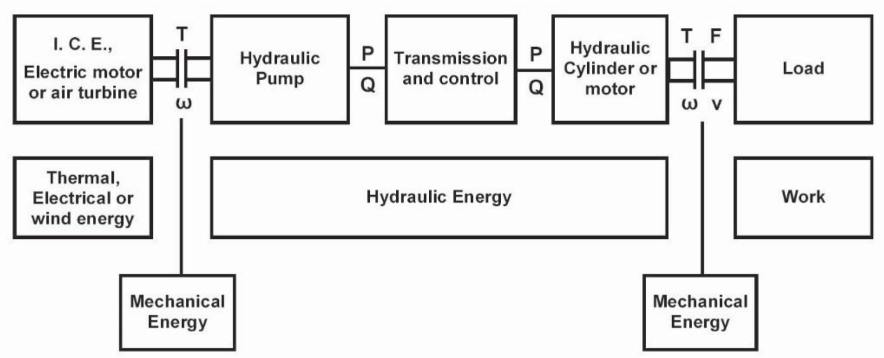


Fig.1.8 Power Transmission in hydraulic Power System

1.4 ADVANTAGES OF HYDRAULIC SYSTEMS

The main advantages of the hydraulic power systems are the following.

1. High power to weight ratio.
2. Self lubrication.
3. There is no saturation phenomenon in the hydraulic systems compared with saturation in electric machines. The maximum torque of electric motor is proportional to the electric current, but it is limited by the magnetic saturation.
4. High force to mass ratio, and torque to inertia ratio, which result in high acceleration capability and rapid response of the hydraulic motors.
5. High stiffness of the hydraulic cylinders, which allows stopping loads at any intermediate position.
6. Simple protection against overloading.
7. Possibility of energy storage in hydraulic accumulators.
8. Flexibility of transmission compared with mechanical systems.
9. Availability of both of rotary and rectilinear motions.
10. Safe regarding the explosion hazard.

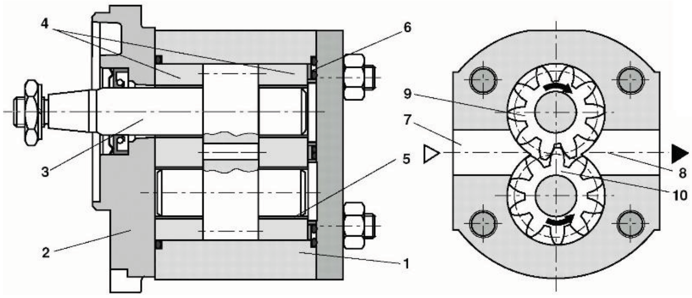
The hydraulic power systems have the following disadvantages.

1. The hydraulic power is not readily available, as the electrical one. Hydraulic generators are therefore required.
2. High cost of production due to the requirements of small clearances and high precision production process.
3. High inertia of transmission lines which increases their response time.
4. Limitation of the maximum and minimum operating temperature.
5. Fire hazard when mineral oils are used.
6. Problems of oil filtration.

Question 2 **(25 points)**

i. Explain briefly the construction and operation of the given pump.

a)



1. Housing, 2**.** Mounting flange, **3.** Drive shaft, 4. Two bearing blocks, side plates, 5. Bearing bush, 6. Discs, 7&8. Inlet and exit ports, 9. Driving gear, 10. Driven gear

Gear pumps are of multi-rotor displacement type. There are four main types of gear pumps; external gear pumps, internal gear pumps, screw pumps and gerotors. The External gear pumps, Fig.4.22, consist of the housing **1**, mounting flange **2**, drive shaft **3**, two side plates, **4**, bearing bush **5**, two gears **9**&**10** and disc **6**. The driving gear **9** is connected to the driving shaft **3.** The pumping chamber is formed by the surfaces of two adjacent teeth, the inner surface of housing and the two side plates. During the rotational movement of the gears, the un-meshing gears release the pumping chambers. The resulting under pressure, together with the pressure in the suction line, forces the fluid to flow to the pump inlet port **7**. This fluid fills the pumping chambers, then, it is moved with the rotating gear from the suction side to the pressure side. Here the gears mesh once more and displace the fluid out of the pumping chambers and prevent its return to the suction zone.

ii. Write an expression for the geometric volume (displacement) of this pump, giving the meaning and units of all of the used symbols.

In the case of external gear pump with two spur gears, the pump geometric volume is given by the following relation.

$$V_g = 2\pi b m^2 (z + \sin^2 \gamma) \qquad (4.30)$$

b = Tooth length, m
m = Module of tooth, m
z = Number of teeth per gear
γ = Pressure angle of tooth, rad
V_g = Pump displacement, m^3/rev

b) Calculate the displacement volume, input power, leakage flow rate, resistance to internal leakage and driving torque of a gear pump of the following parameters.

Pump speed =1450 rpm, number of teeth = 12, tooth module = 3.5 mm, Tooth width = 20 mm, pressure angle = 20°, inlet pressure = 0.2 MPa, exit pressure = 15 MPa, mechanical efficiency = 0.85 and volumetric efficiency = 0.9. Calculate the volumetric efficiency if the pressure is increased to 220 bar.

$$V_g = 2\pi b m^2 (z + \sin^2 \gamma) = 1.865 \times 10^{-5} m^3$$

$$Q_t = V_g n = 4.51 \times 10^{-4} m^3 / s$$

$$Q = Q_t \eta_v = 4.06 \times 10^{-4} m^3 / s$$

$$T = \frac{V_g}{2\pi \eta_m \eta_h}(Po - Pi) = 51.69 Nm$$

$$N_{in} = 2\pi n T = 7.848 kW$$

$$Nh = P_o Q = 6.085 kW$$

$$Q_L = Qt - Q = 4.51 \times 10^{-5} m^3 / s m^3 / s$$

$$R_L = (P_o - P_i)/Q_L = 3.28\times10^{11}$$

$$\sigma = \frac{\pi^2\cos^2\gamma}{4(z+1)} = 16.8\%$$

The volumatric efficiency at 220 bar is:

$$\eta_{v220} = 1 - \frac{220\times10^5}{R_L V_G n} = 0.851$$

Rules

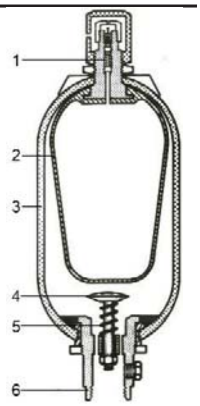
Status	Rule
* Unsat	gama=20*pi()/180
* Unsat	Vg=2*pi()*b*m*m*(z+(sin(gama))^2)
* Unsat	Qt=Vg*n
* Unsat	Q=Qt*etav
* Unsat	T=(Po-Pi)*Vg/(2*pi()*etam*etah)
* Unsat	Nin=2*pi()*n*T
* Unsat	Nh=Po*Q
* Unsat	QL=Qt-Q
* Unsat	RL=(Po-Pi)/QL
* Unsat	etav220=1-2.2e7/(RL*Vg*n)

Variables

Status	Input	Name	Output
	12	z	
	24.1666667	n	
	.9	etav	
	.85	etam	
	15000000	Po	
	.02	b	
	.0035	m	
	1	etah	
	200000	Pi	
		gama	.34906585
		Vg	1.86526E-5
		Qt	.000450772
		Q	.000405695
		T	51.6896017
		Nin	7848.73752
		Nh	6085.42318
		QL	4.50772E-5
		RL	3.28326E11
		etav220	.851351351

Question 3 (25 points)

a) i. Explain the construction and operation of the given accumulator.



In this class of accumulators, a bladder is used as the elastic separation of the oil and compressed gas. The bladder is fastened inside the steel body by means of the vulcanized gas-charging valve assembly. It can be removed and replaced through an opening in the steel body at the oil-valve assembly. Initially, the bladder is charged with compressed gas while the oil port is drained. The bladder is stretched until it comes in contact with the vessel walls.

The bladder material withstands high compression stresses, but its resistance to shear and tensile stresses is very low. Therefore, the bladder is protected against extruding through the oil connection port by one of two different ways:

- Closing the oil port by a hemispherical steel plate with great number of small diameter holes allowing for free oil flow. The holes diameter is too small that the resulting shear stress acting on the bladder walls is less than the allowable value.
- Using a mushroom shaped protection valve which seats when the bladder is pre-charged.

When pumping the oil to the accumulator at pressures higher than the pre-charge pressure, the oil enters the accumulator, compressing the gas and reducing the bladder volume. The internal tightness of the bladder accumulator is perfect as long as the bladder is not damaged.

ii. Define the volumetric capacity of hydraulic accumulator.

The volumetric capacity of accumulator; V_a is defined as the volume of oil delivered to/from the accumulator at pressure P in the operating range; $P_1 \le P \le P_2$.

iii. Derive an expression for the accumulator volumetric capacity.

The following equation describes the gas compression process.

$$P_o V_o^n = P_1 V_1^n = P_2 V_2^n = const. \qquad (6.2)$$

According to the type of compression process, the value of the exponent **n** varies in the range from 1 to 1.4. For isothermal process, n=1, for polytropic process, 1<n<1.4 and for adiabatic process, n= γ =1.4. The pressure is absolute, whenever a gas process is considered. If the compression process is so slow that the gas temperature is kept constant, the process is isothermal and the gas pressure and volume are related by the following relation.

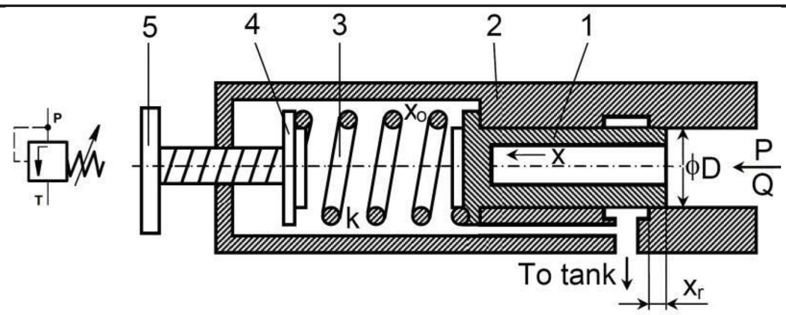
$$P_o V_o = P_1 V_1 = P_2 V_2 = Const. \qquad (6.3)$$

$$V_a = V_1 - V_2 = V_o \left\{ \left(\frac{P_o}{P_1} \right)^{\frac{1}{n}} - \left(\frac{P_o}{P_2} \right)^{\frac{1}{n}} \right\} \text{For polytropic process} \quad (6.4)$$

$$V_a = V_1 - V_2 = V_o \left\{ \left(\frac{P_o}{P_1} \right) - \left(\frac{P_o}{P_2} \right) \right\} \text{ For isothermal process} \quad (6.5)$$

Where,
P_o =Accumulator charging pressure, gas pressure, Pa (abs)
P_1 =Minimum system pressure, Pa (abs)
P_2 =Maximum system pressure, Pa (abs)
V_o =Accumulator size, volume of charging gas at pressure P_o, m^3
V_1 =Volume of gas at pressure P_1, m^3
V_2 =Volume of gas at pressure P_2, m^3

b)



i. Explain the construction and operation of the shown valve

This is a direct operated relief valve. The Poppet 1 is acted on by the spring 3. The pre0compression distance of the spring is pre-set by the rotating handle 5. Initially, the poppet rests against the hosing 2 shoulder. It disconnects the inlet port from the tank port. As the pressure P increases, the pressure force acting on the poppet increases ($F_p=\pi D^2P/4$). As the pressure force F overcomes the spring force kx_o, the poppet starts to move to the left. When the pressure P equals the cracking pressure P_r, the popper should have displaced by x_r as $\{P_r=k(x_o+x_r)*4/(\pi D^2)\}$. For pressures greater than P_r, the valve opens, allowing the oil from the high-pressure port to flow to the tank.

ii. Derive an equation for the valve flow rate then draw and discuss its flow-pressure characteristics. Explain how to reduce the over-ride pressure.

Considering the valve shown in Fig.5.2, the relation between the valve flow rate and system pressure is deduced in the following.

$$P_r = \frac{k}{A_P}(x_o + x_r) \tag{5.2}$$

Then $\quad x_r = P_r \frac{A_P}{k} - x_o \quad$ Or $\quad x_o + x_r = \frac{A_P}{k} P_r \qquad (5.3)$

$$A_P = \pi D^2 / 4 \tag{5.4}$$

Neglecting the spool radial clearance leakage, then;

$$Q = \begin{cases} 0 & \text{for } x \le x_r, \quad A_v = 0 \\ C_d A_v \sqrt{2P/\rho} & \text{for } x > x_r, \quad A_v = \omega(x - x_r) \end{cases} \tag{5.5}$$

In the steady state, the valve poppet becomes in equilibrium under the action of the pressure forces, spring force and jet reaction forces. Neglecting the jet reaction forces and assuming zero return line pressure, then when the pressure increases such that the spool displaces by a distance x;

$$PA_P = k(x_o + x) \qquad \text{Then} \qquad x = P\frac{A_P}{k} - x_o \tag{5.6}$$

$$A_v = \omega\left(P\frac{A_P}{k} - x_o - x_r\right) \qquad \text{Or} \qquad A_v = \omega\frac{A_P}{k}\left(P - P_r\right) \tag{5.7}$$

Then $\quad Q = C_d \omega \frac{A_P}{k}\left(P - P_r\right)\sqrt{2P/\rho} = K(P - P_r)\sqrt{P} \qquad (5.8)$

$$K = C_d \omega \frac{A_P}{k}\sqrt{2/\rho} \tag{5.9}$$

A_v =Valve throttling area, m^2
C_d =Discharge coefficient.
P =Valve input pressure, Pa.
x =Spool displacement, m
x_r =Spool overlap, m
ω =Valve throttling area proportionality coefficient, m.

The steady state characteristics of the valve are described by the pressure-flow rate relation, shown in Fig.5.3. This figure shows that the maximum pressure P, corresponds to the relieved flow rate Q_r. The pressure difference ($P–P_r$) is called the over-ride pressure. At a pressure $P=P_r$, the poppet is in equilibrium under the action of the pressure and spring pre-compression forces. The valve is closed and its flow rate is zero, assuming no leakage. In order to allow the oil to flow, the poppet should displace, which takes place at pressures higher than P_r. This increase in pressure is the over-ride pressure. For higher flow rates, the over-ride pressure is higher.

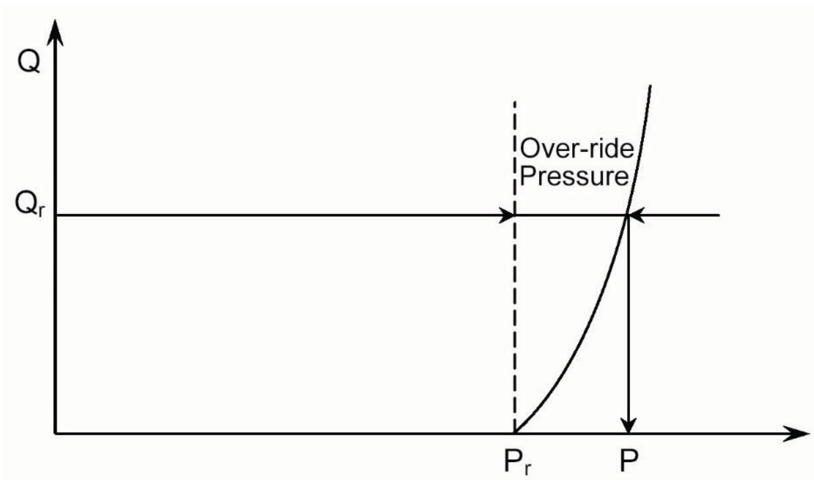


Fig.5.3 Static characteristics of relief valve

The over-ride pressure could be decreased by increasing the slope of the flow-pressure curve, by increasing the value of parameter H; $K = C_d \omega \frac{A_P}{k}\sqrt{2/\rho}$. This could be achieved by increasing the valve dimensions and decreasing the spring stiffness.

Question 4 **(25 points)**

a) State the applications of hydraulic accumulators in hydraulic systems.

1. **a)** Reserve source of energy
   b) Compensation of the short duration large flow demands; to reduce the required pump size and the driving power.
   c) Pump unloading.
   d) Reducing the response time of actuators placed at long distance from the pump.
2. Maintaining constant pressure; compensation for leakage losses
3. Thermal compensation
4. Smoothing of the pressure and flow pulsation
5. Load suspension on load transporting vehicles
6. Absorption of hydraulic shocks
7. Hydraulic spring in the car suspension

b) Write the equations describing the steady state operation of hydraulic motors.

The function of hydraulic motors is the reverse of that of the pump. Hydraulic motors are displacement machines converting the supplied hydraulic power into mechanical power. They perform continuous rotary motion. The displacement (or geometric volume) of a hydraulic motor is the volume of oil needed to rotate the motor shaft by one complete revolution. The motor speed depends on the flow rate, while the supply pressure depends mainly on the motor loading torque. In the case of an ideal motor with no leakage and no friction, the following relations are used.

$$n_m = Q_t / V_m \qquad (7.13)$$

$$\Delta P = \frac{2\pi}{V_m} T \qquad (7.14)$$

where
n_m =Motor speed, rev/s
ΔP =Applied pressure difference, Pa
V_m =Geometric volume of motor, m^3/rev
T =Loading torque, Nm
Q_t =Theoretical flow rate, m^3 /s.

The theoretical motor flow rate is less than the real flow due to the internal leakage. The volumetric efficiency of motor is defined as follows.

$$\eta_v = \frac{Q_t}{Q} \qquad (7.15)$$

Or $$n_m = \frac{Q\eta_v}{V_m} \qquad (7.16)$$

$$Q\Delta P\eta_T = 2\pi n_m T \qquad (7.17)$$

Then; $$\Delta P = \frac{2\pi}{V_m \eta_m \eta_h} T \qquad (7.18)$$

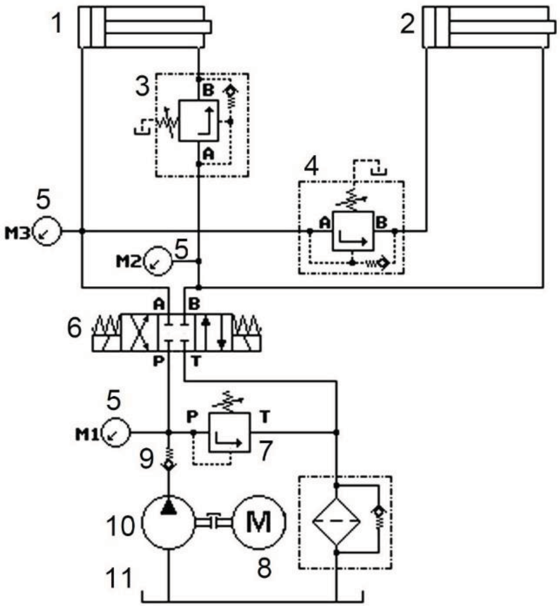
where
Q =Real motor flow rate, m^3 /s
η_T =Total motor efficiency

η_m =Motor mechanical efficiency

η_v =Motor volumetric efficiency

η_h =Motor hydraulic efficiency

c) Explain the construction and operation of the given hydraulic circuit.



Components of the system:

1 and 2 hydraulic cylinders, 3 and4 sequence valves, 5 pressure gages, 6 4/3 directional control valve, 7 safety valve, 8 electric motor, 9 check valve, 10 pump and 11 hydraulic tank.

Operating modes

1. With DCV in the neutral position. All of the DCV ports are closed. The pump delivery line, being closed, forces the pump glow through the relief calve. The pump exit pressure is maximum.
2. With the DCV in the left position, Cylinder 2 retracts. The fluid flows from cylinder 2 to the tank through the check valves mounted in parallel to the sequence valve 4. When the cylinder 2 is stopped or its load increases to the level pre-set at the sequence valve 3, cylinder 1 will retract.
3. With the DCV in the right-hand position, cylinder 1 starts to extend. The sequence valve 4 is closed, preventing the pressurized oil supply from reaching cylinder 2. When cylinder 1 reaches its end position, or its load increases, causing the pressure to increase to the pre-set value on sequence valve 4, it opens. The pressurized oil reaches cylinder 2, which extends.

Give the meaning and units of all of the used symbols.

The neatness and good organization of your exam paper are evaluated

GOOD LUCK

Ministry of Higher Education
Modern Academy
For Engineering & Technology in Maadi

وزارة التعليم العالى
الأكاديمية الحديثة
للهندسة والتكنولوجيا بالمعادى

Written Examination and Written Examination Results Evaluation

1. Examination header: *(should be according to the Modern Academy Format)*

Modern Academy
for Engineering and Technology in Maadi
Manufacturing Engineering and Production Technology Department

Academic Year	2015-2016
Semester	First
Exam Date	11/1/2016

QUESTIONS FOR THE FINAL WRITTEN EXAM

Subject: (M578) Hydraulic Power Systems **Spec.:** 5th Man. Eng. & Prod. Tech.
Examiners: Prof. M. Galal Rabie & Dr. Abdelmegid Abdellatif **Time:** 3 hours

Number of Pages: 2 Number of Questions: 4 Attempt all questions

2. Evaluated ILO's

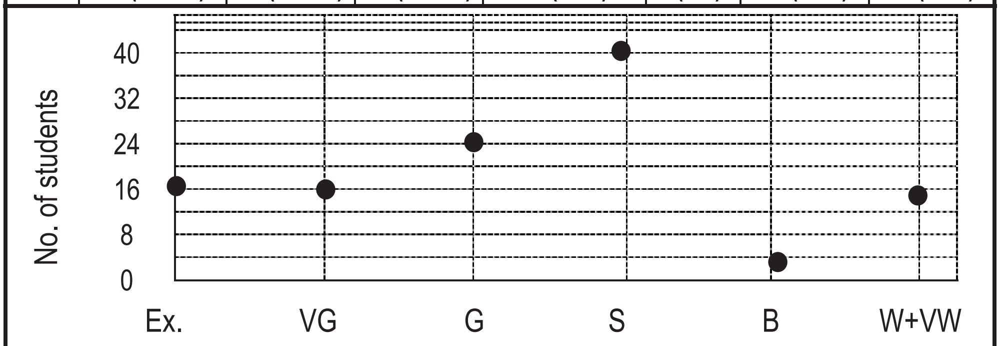
		Quest.1	Quest.2	Quest.3	Quest.4
Maximum points		25	25	25	25
Covered ILO's	Knowledge & understanding (a1 to a 6)	2,4, 5	2,4	2,4	2,4,5
	Intellectual skills (b1 to b 3)	2,3	2,3	2,3	2,3,4
	Practical applied skills (c1 to c 5)	2	2	3	2
	General transferrable skills (d1 to d 4)	2	2	2	2
Success %		89	83	68.8	60.7
Average points%		72.5	67.6	58.8	54.6
Highest mark %		100	100	100	100
Lowest Mark %		28	0	0	0

3. Comment on the ILO's covered by the exam

- The exam paper header agrees with the MAM standard form
- The exam paper measures 73% of course ILO's measurable in written form and the variety of questions is practically balanced.
- The exam considers the course aims listed in the course specification.

4. Collective examination results

Grade	Ex.	VG	G	S	F		
					BL	W+VW	Total
No.	**16 (14.3%)**	**15 (13.4%)**	**25 (22.3%)**	**37 (33%)**	**3(3%)**	**16 (14%)**	**19 (17%)**



5. Comment on the Examination results and feedback

- The exam level is practically convenient, considering the percentage of success.
- Low success percentage in questions 3 and 4 may be attributed to low attendance during the second half of semester. Moreover, it implies the need to develop new plans to encourage the students, or oblige them, to attend the late term activities.
- The exam result shows considerable weakness in hand sketching and report writing and English language level.
- The exam showed acceptable level in manipulation with numbers. However, a non-negligible percentage of students suffer from poor comprehension of SI units and numbers evaluation.

عميد الأكاديمية رئيس القسم أستاذ المادة

Annual Course Report
Academic year 2014-2015

A- Basic Information

1- Course Code & Title: (M578) Hydraulic Power Systems
2- Program(s) on which this course is given: Production Engineering and manufacturing Technology BSc Program
3- Year/Level of program: Fourth Year/Second Semester
4- Credit hours

Total	7hrs	Lectures	3 hrs	Tutorial	2 hrs	Practical	2 hr

5- Names of lecturers contributing to the delivery of the course: Prof. Dr. M Galal Rabie
6- Course coordinator: Prof. Dr. M Galal Rabie
7- External evaluator: Non

B- Statistical Information

1- No. of students attending the course:	**No.**	**53**	**100 %**
2- No. of students completing the course:	**No.**	**50**	**94 %**

3- Results:

	No.	%
Passed	44	88
Failed	6	12

Grading of successful students:		
Grade	No.	%
Excellent	0	0
Very Good	8	18.2
Good	14	31.8
Pass	22	50

C- Professional Information

1 – Course teaching

Topic	Total hours		Lecturers
	Plan.	**Actual**	
➢ Power systems, classification, operation, and comparison.	4	The effective teaching weeks during this semester were 12 with total of 84 hours. Therefore, a balanced reduction of teaching hours by 20% was	Prof. Dr. M Galal Rabie
➢ Introduction to hydraulic power systems and standard symbols	10		
➢ Hydraulic fluids; properties and their effect on the system performance.	4		
➢ Hydraulic transmission lines and connectors	10		
➢ Hydraulic pumps:	4		
• Classification and basic mathematical relations	4		
• Gear pumps, vane pumps and piston pumps	4		
• Fixed and variable displacement pumps and pump control	4		
➢ Control valves	4		
• Classification and basic design			
• Pressure control valves (direct/pilot operated); relief valves, pressure reducers, sequence valves and accumulator charging valves	6		
• Directional control valves	4		
• Flow control valves	4		
• Check valves	5		
➢ Hydraulic actuators; cylinders, motors and rotary actuators	2		
➢ Accessories; accumulators, filters, reservoirs, pressure switches,…etc	4		

➢ Small project; design and analysis of the hydraulic system for an industrial application. Analysis of the possible operational problems...	6		
Total hours	105	84	

- Topics taught as a percentage of the content specified: >90 % 70-90 % <70%
- Reasons in detail for not teaching any topic: Non
- If any topics were taught which are not specified, give reasons in detail: Non
- Achieved program intended learning outcomes, ILO's: Actually, all of the intended learning outcomes were achieved. The 20% obligatory cut of the net teaching hours was partially compensated by additional reports and seminars.

Knowledge & Understanding	Intellectual skills	Applied Skills	General transferable skills
a1 to a6	b1 to b3	c1 to c5	d1 to d4

2- Teaching and learning methods:

lecture, presentations & movies, discussions & seminars, tutorials, problem solving and self-learning, modeling

If teaching and learning methods were used other than those specified, give reasons: Non

Seminar/Workshop:

The following are two seminars arranged by 8 students and 13 Technical Reports by 66 students:

Seminars

No.	Title	Number of students
1	Using Automation Studio in hydraulic system design	4
2	Using NFPA educational CD for training on hydraulic power systems	4
3	Reading data sheets of hydraulic elements	4
4	Using Water as a Hydraulic Liquid	3

Technical Reports

SN	Title	Number of students
1.	Displacement pumps	2
2.	Rotodynamic Pumps	2
3.	Pressure Control Valves	2
4.	Flow rate control valves	2
5.	Hydraulic cylinders	2
6.	Electric Motors	2
7.	Hydraulic Motors	2
8.	Hydraulic Motors	2

3- Student assessment:

Tools	To measure the content of	Time schedule	Grading	%
Mid-Term Exam	a1 to a6, b1 to b3 and c1 to c4	sixth week	15	10
Term papers, quizzes and seminars	a1 to a5, b1 to b3, c1, c2 and c4 and d1 to d4	Bi-weekly	15	10
Practical exams	a3, c1 and c5	Fifteenth week	20	13.3
Written exam	a1 to a6, b1 to b3 and c1 to c4 and d2	16th week	100	66.7
		Total	150	100

Members of examination committee: Dr. M. Galal RABIE and Dr. Abdelmegid Abdellatif

Role of external evaluator: Non

4- Facilities and teaching materials:

Totally adequate	Yes
Adequate to some extent	
Inadequate	

List any inadequacies: Non

5- Administrative constraints (List any difficulties encountered)

- Non

6. Comment on the Examination results and feedback

* The exam paper header agrees with the MAM standard form
* The exam paper measures 65% of course ILO's measurable in written form and the variety of questions is practically balanced.
* The exam considers the course aims listed in the course specification.
* The exam level is practically convenient, considering the percentage of success.
* Low success percentage in questions 3 and 4 may be attributed to low attendance during the second half of semester. Moreover, it implies the need to develop new plans to encourage the students, or oblige them, to attend the late term activities.
* The exam result shows considerable weakness in hand sketching and report writing and English language level.

7- Student evaluation of the course:

	List any criticisms	Response of course team
(a)	Non	

8- Comments from external evaluator(s):

	Comment	Response of course team
(a)	Non	

9- Course enhancement:

Progress on actions identified in the previous year's action plan. State whether or not completed and give reasons for any non-completion:

Actions required	Planned Completion date	Accomplishment
Non		

10- Action plan for academic year 2013 – 2014

Actions required	**Completion date**	**Person responsible**

Course coordinator: Prof. Dr M Galal Rabie

Signature:

Date: July 24, 2015

The files are kept for five years in this box, then the older year’s files are replaced

Academic Year: 2014-2015

	Mid-term exam paper
	Model answer for the mid-term exam
	Corrective exam paper
	Model answer for the corrective exam
	Final written exam paper
	Model answer for the final written exam
	Final written exam evaluation and exam result analysis
	Students course-questionnaire analysis
	November exam paper
	Model answer for November written exam
	Annual course report

Academic Year: 2013-2014

	Corrective exam paper
	Model answer for the corrective exam
	Final written exam paper
	Model answer for the final written exam
	Final written exam evaluation and exam result analysis
	Students course-questionnaire analysis
	November exam paper
	Model answer for November written exam
	Annual course report

Academic Year: 2012-2013

	Corrective exam paper
	Model answer for the corrective exam
	Final written exam paper
	Model answer for the final written exam
	Final written exam evaluation and exam result analysis
	Students course-questionnaire analysis
	November exam paper
	Model answer for November written exam
	Annual course report

Academic Year: 2011-2012

	Corrective exam paper
	Model answer for the corrective exam
	Final written exam paper
	Model answer for the final written exam
	Final written exam evaluation and exam result analysis
	Students course-questionnaire analysis
	November exam paper
	Model answer for November written exam
	Annual course report