Horst Walter Grollius

# Principles of Hydraulics


Second Edition

*“If you can`t explain it simply, you don`t understand it well enough.”*

Albert Einstein

Univ.-Prof. Dr.-Ing. Horst Walter Grollius

Cologne

# Preface

To increase the efficiency of production, knowledge and its application in various engineering disciplines is required. This also includes the **fluid technology** which is subdivided in **hydraulics** and **pneumatics**.

With this book the author especially intends to introduce the reader in the principles of hydraulics.

Recourse is made on the book “Grundlagen der Hydraulik” (chapter 2) published by the author in the German language. This book appears in the CARL HANSER-Verlag and is now in the 7$^{th}$ edition.

The book presented here, offers the possibility familiarizing themselves without spending too much time with the **principles of hydraulics**. This particularly applies for students at universities and technical schools. In addition the book will also be of help for those readers which are as technicians in professional practice and want to refresh their basic skills in the field of hydraulics.

In the last chapter the reader will find 10 examples with the detailed presentation of the solution path by the “step by step” method (each step is commented); clarity of the path to find the solution is thus given.

May the study of this book not only make effort, but rather have also motivated the reader to delve with additional literature in this fascinating and economically important field of technology.

Furthermore, many thanks to the company TENADO GmbH (Bochum, Germany); the TENADO CAD software of this company has been used for the creation of all figures shown in the book.

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*Horst Walter Grollius*

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**Sources of Literature**

## Symbols

Symbols used in the book and not found in the following list will be explained by the book text.

| | | |
|---|---|---|
| $A$ | Area | $m^2$ |
| $B$ | Width | m |
| $b$ | Correction factor, gap width | -, m |
| $C$ | Flow coefficient | - |
| $d$ | Inner diameter (hydraulic cylinder) | m |
| $dA$ | Area (infinitesimal small) | $m^2$ |
| $dF$ | Force (infinitesimal small) | N |
| $d_e$ | Hydaulic diameter | m |
| $d_{PR}$ | Piston rod diameter | m |
| $E$ | Modulus of elasticity | $N/m^2$ |
| $F$ | Force | N |
| $F_P$ | Piston Force | N |
| $G$ | Weight | N |
| $g$ | Acceleration of gravity | $m/s^2$ |
| $h$ | Height coordinate, gap height | m, m |
| $I$ | Electrical current | $A$ |
| $K$ | True compression module | bar |
| $K_S$ | Average compression | bar |

| | | |
|---|---|---|
| | module | |
| $k$ | Absolute wall roughness, correction value | m, - |
| $k$ / $d$ | Relative pipe roughness | - |
| $l$ | Pipe length, gap length | m, m |
| $m$ | Mass | kg |
| $\dot{m}$ | Mass flow | kg/s |
| $P$ | Hydraulic power | kW |
| $p$ | Pressure | $N/m^2$ |
| $p_{abs}$ | Absolute pressure | $N/m^2$ |
| $p_{amb}$ | Atmospheric pressure | $N/m^2$ |
| $p_e$ | Overpressure (or gauge pressure) | $N/m^2$ |
| $p_I$ | Inlet pressure (hydraulic pump, hydraulic motor) | $N/m^2$ |
| $p_O$ | Outlet pressure (hydraulic pump, hydraulic motor) | $N/m^2$ |
| $Q$ | Volume flow or flow rate | $m^3/s$ |
| $R$ | Spring rate, hydrostatic resistanse | N/m, $kg/(m^4 \cdot s)$ |
| $R_{tot}$ | Total hydrostatic resistance | N/m, $kg/(m^4 \cdot s)$ |
| $Re$ | *Reynolds*- number | - |
| $Re_{crit}$ | Citical *Reynolds* -number | - |
| $s$ | Way | m |

| | | |
|---|---|---|
| $T$ | Torque | Nm |
| $t$ | Time, temperature | s,º C |
| $U$ | Perimeter, electrical Voltage | m, V |
| $V$ | Volume | m 3 |
| $\upsilon$ | Velocity | m/s |
| $\upsilon_m$ | Average velocity | m/s |
| $\upsilon_{max}$ | Maximum velocity | m/s |
| $\upsilon$Plate | Plate velocity | m/s |
| $\upsilon_{crit}$ | Critical velocity | m/s |
| $W$ | Hydraulic work | Nm |
| G | Ratio of diameters | - |
| $ß_P$ | Isothermal copressibility coefficient | 1/bar |
| $\Delta p$ | Pressure difference | $N/m^2$ |
| ζ | Flow resistance coefficient | - |
| η | Dynamic viscosity | $N\text{-}s/m^2$ |

NOTE: For the physical variables used in this book the **International System of Units** (SI) is used. For conversion into units used in Anglo-Saxon countries, conversion tables have to be used, which are available in the web.

# 1 Introduction

Fluid power is the generic term for the areas of hydraulics and pneumatics. In the area of hydraulics the fluids are liquids; in the area of pneumatics gas is used, namely air. In the beginnings of the hydraulics water was used as the fluid for energy transfer. Since the beginning of the 20$^{th}$ century oils are used. These have lubrication- and corrosion protection in addition. For some years water is also reused as the fluid for energy transfer in individual cases for reasons of environmental protection and costs, also called “water hydraulics”. The present book deals mainly with the **physical principals** relevant for oil-operated hydraulic systems (usually mineral oils are used).

The oil-hydraulic is divided into the areas of **hydrodynamic** and **hydrostatic** energy transfer.

The **hydrodynamic energy transfer** uses an impeller in order to transfer mechanical energy to the oil. The flow energy of the oil is used to drive a turbine wheel. These systems are called **hydrodynamic drive** systems (for example Föttinger converters and Fluid couplings).

In the case of the **hydrostatic energy transfer,** a mechanically driven pump (hydraulic pump) produces a mainly pressure-loaded volume flow which is supplied to a hydraulic cylinder or a hydraulic motor. Therein, the pressure energy is reconverted into mechanical energy. These are called **hydrostatic drive** systems.

The kinetic energy is negligible in systems with hydrostatic transfer energy compared to the pressure energy.